Human Factors and Ergonomics in Consumer Product Design

Methods and Techniques

Edited by
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CRC Press
Taylor & Francis Group

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

International Standard Book Number-13: 978-1-4200-4629-8 (eBook - PDF)

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Preface

Every day, we interact with thousands of consumer products. As users, we expect these products, no matter how simple or complex, to perform their expected functions in a safe, reliable, and efficient manner. Unfortunately, this is not always the case, as designing consumer products that satisfy human needs and expectations is not an easy task. The design process that involves the application of human factors and ergonomics (HF/E) principles and knowledge strives to achieve the above goals and, at the same time, reduce the risk of product malfunction or failure, reduce the potential for accidents, and contribute to overall product acceptance and utility, all while reducing the total product life cycle cost.

HF/E is a unique and far-reaching discipline that focuses on the nature of human–artifact interactions, which are viewed from a unified perspective on science, engineering, design, technology, and management of human-compatibility systems (Karwowski 2005). The HF/E discipline promotes a holistic, human-centered approach that considers physical, cognitive, social, organizational, environmental, and other design-relevant factors. As such, HF/E aids designers by raising their awareness of the full scope of knowledge required when designing consumer products, and plays an important role in facilitating a better performance of consumer products in general. HF/E-based design of products encompasses a wide variety of consumer preferences, and accounts for differences in such preferences due to factors such as age, gender, or health issues.

The goal of the human-centered design paradigm as applied to consumer products is to improve levels of user satisfaction, efficiency of use, increase comfort, and assure safety under normal use as well as foreseeable misuse of the product. It is in this context that we are very pleased to present the first volume of the *Handbook of Human Factors and Ergonomics in Consumer Product Design*. The motivation to produce this *Handbook* was to facilitate wider acceptance of HF/E as an effective body of knowledge for improving quality of life and safety for millions of users of consumer products with a variety of needs and expectations. In this *Handbook*, consumer products are defined as those goods used by the general public without any special training, skills, or supervision. Consumers are individuals of any age, gender, or physical condition with varying educational, cultural, and economic backgrounds. Consumer products are usually used in or around the home, in a social setting, rather than in a workplace environment with commercial needs.

Currently, there is substantial and convincing evidence that the application of HF/E knowledge can improve critical features of consumer products. These features include: ease of use, ability to learn product functions, efficiency, comfort, safety, and adaptability, all of which meet the needs and contribute to consumer satisfaction. Therefore, this two-volume *Handbook* aims to offer a comprehensive review of the HF/E state of the art relevant to design, development, testing, evaluation, and use of consumer products. The *Handbook* also aims to provide a comprehensive source of information regarding new methods, techniques, and software applications for consumer product design.

The first volume, *Human Factors and Ergonomics in Consumer Product Design: Methods and Techniques*, contains 29 chapters divided into four sections. Section I contains information about a variety of methods and techniques that can be applied in product design. These include the user-centered design approach, starting with a definition of users, the tasks they perform, and a way to translate design research into useful and usable products. Also included are chapters about human design technology, consumer products conceptual design, and development of smarter products using a systems engineering approach.

Section II, which contains 13 chapters, discusses the user-centered design process, starting with a discussion of how mental workload affects every day interactions with consumer products, and what lessons may be applied to product design. Other chapters focus on the various aspects of creativity, innovation, standards and guidelines, culture, environment, affect, aging, and complexity in product design process.

Section III contains six chapters that consider the ever-increasing role of information technology, including digital imaging, video and other media, and virtual reality applications in consumer product design. Finally, section IV contains five chapters focusing on a variety of user-centered aspects of consumer product development. These chapters discuss such topics as user-centered vs. task-based approach, articulation and assessment of user requirements and needs, interaction with design models, as well as eco-design.

We hope that this first volume will be useful to a large number of professionals, students, and practitioners who strive to incorporate HF/E principles and knowledge in the design of consumer products in a variety of applications. We also hope that the knowledge presented in this volume will ultimately lead to an increased appreciation of the benefits of the HF/E discipline by ordinary consumers of the myriad of products used every day, and increase the HF/E literacy (Karwowski 2007) of citizens around the world.

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REFERENCES

Karwowski, W. 2005. Ergonomics and human factors: The paradigms for science, engineering, design, technology, and management of human-compatible systems. *Ergonomics* 48 (5): 436–63.

———. 2007. Toward an HF/E-literate society. *Bulletin of the Human Factors and Ergonomics Society* 50 (2): 1–2.

Acknowledgments

The editors would like to take this opportunity to express their sincere appreciation to Madelda Thompson for her invaluable help and assistance in editing the final draft of the *Handbook of Human Factors and Ergonomics in Consumer Product Design*. Marcelo Soares would also like to acknowledge the CNPq – Brazilian National Council of Research and Development, which sponsored his post doctorate research conducted at the Department of Industrial Engineering and Management Systems at the University of Florida, Orlando, USA, and Nalva and Gabriel Soares for their love and unfailing encouragement, support, and patience.

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Section I

Methods for Consumer Products Design

1 Techniques to Translate Design Research into Useful, Usable, and Desirable Products

Elizabeth Mauer and Corinna Proctor

CONTENTS

1.1 INTRODUCTION

Developing successful new products or even redesigning existing products is never an easy process. As human factors professionals, we often advocate field research before starting a design as an excellent way to understand our users. We read about other companies that have conducted field research projects as part of the product development process, wherein the resulting product was so fantastic that it increased the company's stock price, saved the company untold amounts of money, and/or awards and accolades rained down on them for their creativity and innovation. We present stories like these to our clients as examples of how field research can help their products, too.

However, most experienced practitioners know this is not how projects usually go. Conducting design research is a messy, expensive process. What designer hasn't been excited to go into the field and learn about a new product/process/user/industry, only to have that feeling turn to sheer panic as the data start flowing in at a manic rate? The data collected are messy, not easily digestible, and in all different formats. How do you turn all that mess into new product ideas or redesign efforts that will knock your client's socks off and make them feel like it was money well spent?

The reality is that most designers are overwhelmed at this point. The amount of data they have collected can be mind-boggling, and just making sense of it all can seem like an insurmountable task, particularly when clients are eagerly awaiting the answers they are so excited about and have been wondering about for months. Of course, just as this wave of panic is spreading, the client will call you and ask if you have a quick summary or want to schedule a call/presentation to go over the results. What you want to avoid is latching on to a few salient themes you remember from your time in the field and to avoid making conclusions based on only vague memories. This could result in unused data and raise questions about time and money spent.

So how can you avoid this? At each stage of a design research effort, there are techniques you can apply that will (1) narrow down the amount of data collected to just what you are interested in, (2) turn the data you do collect into a coherent story that will serve as a basis for developing new products and/or redesigning existing ones, and (3) save your sanity in the process. This chapter is devoted to the discussion of these techniques, which although not earth-shattering and revolutionary, will help you turn all the data you collect into fantastic new product ideas that just may be earth-shattering and revolutionary (or at least help you avoid the awkward "what did you spend all this money actually doing" conversation with your client).

1.2 STAGES OF DESIGN RESEARCH

1.2.1 Stage 1: Define the Research Plan

Outlining a well-defined, focused research plan is the first step in any successful design research effort. This stage will lay the groundwork for data collection. It is important to do this so that the data you collect will only be what you need and you won't be overwhelmed with unnecessary information later on.

The techniques to use at this stage are affected by

- Amount of time and money available
- Specific goals of the research (i.e., what questions you want to answer)
- Nature of the data to be collected
- Amount of access to users and/or subject-matter experts
- Developing new product vs. redesigning existing product

1.2.1.1 Techniques that Help

1.2.1.1.1 Clearly Establish the Research Goals

The first (and most important) step in any successful design research effort is to clearly establish the research goals. This step will ensure that the team members are on the same page and the clients and other stakeholders are also on board. There is nothing worse than when you finish a research effort and present the findings to a client to begin design, only to find out that you didn't answer the questions they were interested in ("we already knew that—what did you spend all that money on?").

So how can you avoid this? Start by asking your client and other stakeholders what questions they want the research to answer. Most clients have goals in mind—after all, they have to justify to their internal management the reasons for spending the money in the first place. Goals can be at either end of the spectrum, ranging from broad (e.g., "we want to know everything about our small business users") to focused (e.g., "we want to understand the ultrasound workflow and what factors affect it"). The more focused the goals are, the better it is for everyone involved.

If the goals are toward the broad end of the spectrum, you will need to spend some time refining them to make them more focused. A quick and easy way to focus research goals is to create an affinity diagram. This technique is done as a team, and can include members from the client and/or other stakeholders. Each person sits around a table with the broad research goals, a pad of sticky notes, and a pen. For a designated amount of time (perhaps 10 min), each person writes down focused

FIGURE 1.1 A completed affinity diagram.

research questions that fit underneath the broad goals (one question per sticky note). For example, if the broad goal is "we want to know everything about our small business users," then a focused research question might be "how do small business users manage their motor vehicle fleets?" At the end of this time period, the team posts the sticky notes onto a wall for all to see. Start grouping similar questions together. If a question fits into more than one group, write it on multiple sticky notes. When the grouping is completed, give each one a name that describes the research questions in it. Groups of sticky notes can also be combined in a parent–child relationship, but as a general rule of thumb try to keep any hierarchy to three levels or less to prevent overcomplicating the diagram. These final groups represent more focused research goals. If your diagram is showing a lot of hierarchy and research questions, you will need to constrain your own focus for this effort and save the other questions for other projects. This exercise can be repeated until you are satisfied that the goals are sufficiently focused. Figure 1.1 shows an example of a completed affinity diagram.

1.2.1.1.2 Select the Appropriate Data Collection Method

Now that you have focused research goals, the next step is to select the appropriate research methodology (or a series of methodologies) to collect the data that will meet these goals.

When considering the different methodologies, think about the nature of the data you will be collecting. Some methodologies are better suited to collecting certain data than others. Questions to ask yourself and your team include:

- Can you observe the tasks of interest in a short time period or do they occur over a longer time period? For example, processing a benefits form for a new employee can be observed in one session. However, the development of an aircraft occurs over several years and most likely could not be observed in one session.
- Do you need to get information out of people's heads (e.g., "how do you process a benefits form?") or do you need to get information about more musculoskeletal tasks (e.g., "how do you deliver packages?")?
- Is the environment in which you want to collect data mobile (e.g., a delivery driver's truck) or stationary (e.g., a secretary's desk)?

Table 1.1 lists some common research methodologies and some advantages and disadvantages of each to aid in your selection.

TABLE 1.1
Common Research Methodologies

Methodology	Advantages	Disadvantages
Surveys	• Inexpensive • Can reach many respondents	• High-level data • No opportunity for follow-up
One-on-one interviews	• Can yield in-depth data • Opportunities for follow-up	• Moderately expensive • Out of context • Some things hard to elicit from participants
Focus groups	• Participants can build on one another's responses • Quick and easy to assemble • Extreme views can be weeded out/normalized	• Moderately expensive • Can suffer from group think/bias from one dominant participant • Require experienced moderator
Contextual inquiry	• Yields very in-depth data • Lots of qualitative data • Easy to come up with new product ideas • Holistic view of product/process because it is in context	• Expensive • Small sample sizes • Not feasible for collecting longitudinal data • Requires experienced moderator
Comparative analysis	• Can benchmark performance • Shortcomings and strengths identified • Can be inexpensive • Easy to identify gaps in design	• Hard to find commonalities among different products • Hard to come up with truly new product ideas
Usability testing	• Environmental control • Yields quantitative data • Direct observation of problems	• Hard to come up with truly new product ideas • Can be expensive • Setting not naturalistic • Hard to infer reasoning behind problems encountered
Observational research	• Naturalistic setting—users don't know they are being observed • Yields very in-depth data	• No user interaction • No environmental control • Can't predict who you will see

1.2.1.1.3 Develop Data Collection and Analysis Plan

After deciding on a research methodology, the next step is to develop a detailed protocol for your sessions. A protocol is an outline of what will happen in each session, from the beginning introductions to the closing "thank you for allowing us to observe." Sometimes, protocols are also called moderator guides or discussion guides.

A protocol is important because it will keep the session moderators following roughly the same format and makes sure that they collect the right data and observe the right tasks. It ensures consistent formats for each session. It is also important for the user you are observing so that they understand the purpose of the session and what you want from them.

At this step, you will also need to think about what types of data you will be reporting and using in support of the research goals. For example, if you want to report numerical results (e.g., "3/10 users did not use the scanning feature") you will need to make sure that every user is asked the same questions during each session so that your analysis will have a consistent representation from all the participants. Finally, you need to make sure that the data you will be collecting will answer the research questions and goals you've defined.

1.2.1.1.4 Pilot Data Collection and Analysis Plan

We cannot stress the importance of piloting the data collection plan enough. A pilot is essentially a "dress rehearsal" of an entire session from beginning to end. The purpose of it is to allow the session moderators to practice, as well as identifying gaps, mistakes, unnecessary steps, and things that don't belong in the protocol. You will also get an idea of the flow and the length of the session.

A step that is often overlooked is piloting your data analysis plan. Sometimes when a project has a tight timeline, it is tempting to develop your data collection plan, pilot it, and then jump right into actual data collection. It is a good idea to take the data from your pilot session and run through your analysis procedures before beginning actual data collection, to ensure the data collected answer the research questions.

As an example, on a project that had a very tight timeline, we wisely conducted a pilot for our data collection plan. However, we neglected to analyze the pilot results prior to beginning the actual data collection. Before we knew it, we had mounds of data from 24 participants that were in a format that was not conducive to meeting our timeline. As we dug into the analysis stage, we realized that had we piloted our data analysis plan earlier, we could have tweaked the protocol to collect the data in a format that was better suited for more efficient analysis. We were stuck trying to find needles in haystacks. Time and sanity could have been saved with this simple step.

1.2.1.1.5 Collect the Data

Now you are ready for actual data collection. When you begin, be sure to invite all stakeholders to observe. Another good idea is to have team members from different disciplines (including graphic design, industrial design, marketing, and development). A diverse, cross-functional team can help set the stage for innovative and desirable product ideas.

1.2.2 Stage 2: Organize the Data

At this point, the data collection is complete (or nearing completion). If you are like most designers, you and your team are sitting in your office, perhaps surrounded by notes, transcripts, tapes, and assorted equipment. Panic is quickly spreading through you as you think about how you are going to take all those data—your notes, team members' notes, transcripts, pictures, videos—and turn them into something that will be useful for design. Don't be afraid! This happens to even the most experienced designers. The key is to remain calm and not resort to hand wringing or hysterics. If you want to succeed, it is time for action.

You may find it tempting to skip this stage. After all, you are probably exhausted from collecting all those data. Maybe you already have some great ideas based on what you saw. It's much more fun to begin designing right away than to spend more time poring over your data, and you've already seen everything there is to see. Who hasn't thought that?

Our suggestion is to not fall into this trap. Spend time now organizing the data so that they are digestible and addressable in some form. It also establishes a shared understanding of these data on your team. You may already have some great design ideas based on what you saw, but what if another team member says he/she saw something different? Who is correct? At this point neither of you is correct—until you organize your data, you won't be able to know what really happened during data collection. This step provides a complete picture of your data for everyone on your team. Without it, you will focus on a couple of findings that you found particularly interesting or poignant and prematurely make conclusions that might lack support.

There are many techniques that help designers organize their data quickly and efficiently (while saving their sanity). The techniques you choose will depend on

- Amount of time and money available
- Format of data collected (notes, transcripts, pictures, videos, etc.)
- Desired output for team/client

1.2.2.1 Techniques that Help

1.2.2.1.1 Dedicate a Space to Use for the Project

If you are lucky enough to have a dedicated room to use during your project, take it. Ideally, it is equipped with whiteboards, lots of wall space, and a table. You will generate a lot of documents during this process, so having one place to organize everything is very convenient. Your design room can also serve to get your team immersed in the right mindset and thinking about the research as soon as they enter.

If you are like most designers, however, you will have to be more flexible and move around. You can use large pieces of foam core board to display the various documents. These boards can be moved in and out of design rooms while keeping all your documents displayed and together.

1.2.2.1.2 Restate Your Research Goals

Before you start anything, you will need to revisit the goals of the research. This is especially important when the data were collected months or even years before, or when you didn't collect the data to begin with. Refocusing yourself around these goals is crucial at this point, and it will help frame the scheme with which you organize your data. You should naturally begin to organize your data around the different research questions, literally and physically.

One terrific way of doing this is to list the goals of the research on large sheets of paper and pin them high up on the wall of your designated room. Make sure they are phrased clearly and concisely (no one will remember a goal that is longer than a simple phrase or sentence). In this way, the goals remain clearly visible and serve as a constant reminder to the team. For example:

The goals of this study are

- To explore and document the physical environment and typical triggers for printer usage
- To learn what/why people print vs. leaving in electronic form
- To identify the most common usage problems with printers
- To compare printer usage in small, medium, large, and government office environments

1.2.2.1.3 Compile Team Notes in One Document

The best way to begin your data organization effort is to compile all team member notes into a single document. This document provides an overview of all participants across all team members and eliminates having to open multiple documents and flipping back and forth to compare them. This is also a good way to review what occurred in each session, and it doesn't take very long to do. We like to use Microsoft Excel for this task. Put the participants in the rows and the discussion topics from your data collection protocol in the columns. Then combine all notes for each participant on each discussion topic into the relevant cells. Unfortunately, Excel doesn't allow huge amounts of text in a cell, so you may need to summarize the notes to make them fit in a cell.

If you do not have any session notes (because perhaps you didn't collect the data yourself) you will have to go back and watch each video. You can create the Excel spreadsheet and fill it in as you watch each video, recording notes directly to the cells.

Once you create this spreadsheet, it is quite easy to look down a column and see the notes for each participant within a single discussion topic. As you go down, mark anything you deem important or noteworthy for later analysis. You can do this by using different cell colors, making text bold, or any combination of formatting that you like. It is important to be extremely objective during this exercise so that your own memory of the research doesn't bias what you find in the notes.

Do not spend too much time thinking about anything you find just yet; in later stages you will go back through this and decide what it all means. Right now, you are just creating a visual representation of your data so that your eye can quickly find important items during later stages. Figure 1.2 shows an example spreadsheet with compiled notes.

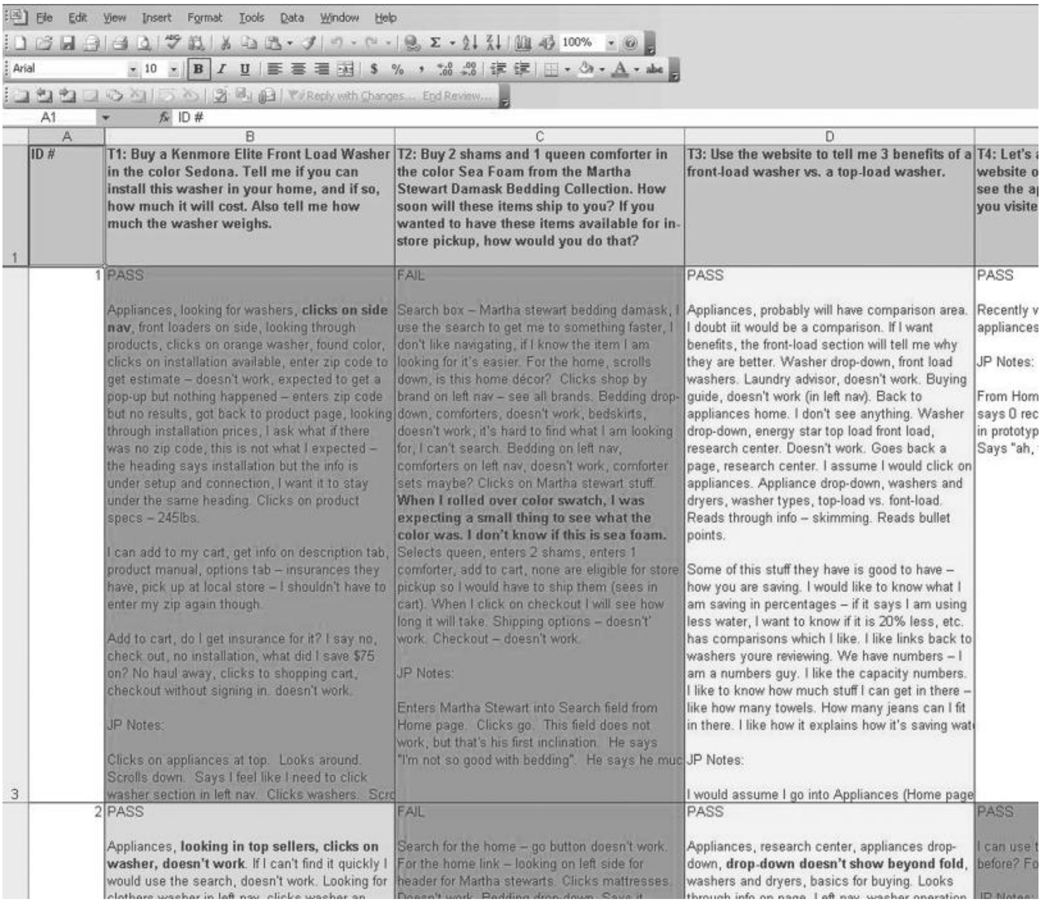


FIGURE 1.2 A sample Excel spreadsheet with all session notes compiled.

1.2.2.1.4 Create an Affinity Diagram

Another quick and easy technique to organize the data is to create an affinity diagram, similar to the way you narrowed down the focus of the research goals in stage 1. The only difference is that each person sits around a table with their research notes and writes down observations onto the sticky notes. The notes are grouped, as they were in stage 1. The final groups are your focus points for the later stages of analysis and design.

This technique can also be done while the team watches videos of the sessions. Although it takes longer, you can glean additional detail that may not be captured in notes or transcripts, particularly about things that don't lend themselves well to textual communication (such as the physical locations of objects or actions a participant performs but does not verbalize).

1.2.2.1.5 Create Work Models

One of the best ways to organize data from field research is to create work models (see Beyer and Holtzblatt (1998) for discussion). These models allow you to visually depict the data in a way that allows you to quickly identify relationships, inconsistencies, redundancies, and omissions. Although they take more time than other techniques, they are well worth the effort if you have the time and money.

Beyer and Holtzblatt define five work models, which we will briefly summarize:

- Flow
- Sequence
- Artifact
- Cultural
- Physical

To create these models, the team sits around a table with a session transcript. If a transcript is not available, have the team watch the session video and pause as appropriate. Designate one person to draw each model on a whiteboard as the team creates them. Everyone goes through the transcript (or video) in chronological order. It is important that everyone stick to what the participant actually said and did, not interpretations of why they said/did that or memory of what they said/did, as much as possible. That way the models will be based on the data observed and not premature interpretations of what you observed.

1.2.2.1.5.1 Flow Model The flow model depicts the people and artifacts with which the participant interacts. It also shows the flow of communication and artifacts between people. To begin the flow model, draw a circle in the middle of the workspace and label it with the participant number (e.g., "User 1"). Any roles and responsibilities the participant assumes (e.g., "Driver," "Navigator," "Parent") are written inside that first circle beneath the participant number. If the participant interacts with another person or group, draw a circle for it, label it with the person or group name, and connect it to the participant's circle with an arrow indicating the direction of the interaction. Place a short phrase on the arrow to describe the interaction. For example, if the participant called tech support, a line would go from the participant's circle to the tech support's circle with the phrase "calls for computer help." If the participant interacts with another object (e.g., computer, desk calendar, printer), draw a rectangle for it, label it with the object name, and connect it to the participant's circle in the same manner. If an object flows between two people (e.g., the participant sends a document to another person), you can place that object in between the two circles. If the participant mentions or experiences a problem with any entity in the flow model, place a red lightning bolt on the line with a short phrase indicating the problem. When this model is complete, you will have a bird's eye view of the participant's organization, showing the people and responsibilities, the communication paths between people, and the things communicated (Beyer and Holtzblatt 1998). Figure 1.3 shows a sample workflow model for a person trying to find a restaurant and make a reservation while driving a car during heavy traffic.

1.2.2.1.5.2 Sequence Model A sequence model represents the set of steps to accomplish the participant's tasks, along with the triggers and the participant's intent for each step. To create this model, start by writing down the participant's overall intent for the task and the trigger that initiated the task. For example, the participant's task may be to read an email, and the trigger for that task is the appearance of the notification icon in the computer's system tray. Underneath the intent and trigger, write down each step the participant took to accomplish it. If there are steps that interfere with or do not support the intent, mark them with a red lightning bolt with a short phrase indicating the problem. When you are finished creating this model, you will have a detailed structure of the work the participant completed, which will be very useful during later stages (Beyer and Holtzblatt 1998). Figure 1.4 shows part of an example sequence model for creating a document for a client.

1.2.2.1.5.3 Artifact Model An artifact model is an annotated drawing of an artifact that a participant uses to complete work. Examples are personal organizers, to-do lists, cell phones, documents, or phone books. They are passed between people and groups in the flow model. To create an artifact model, start by re-drawing it on your whiteboard. Label each part of the artifact's structure.

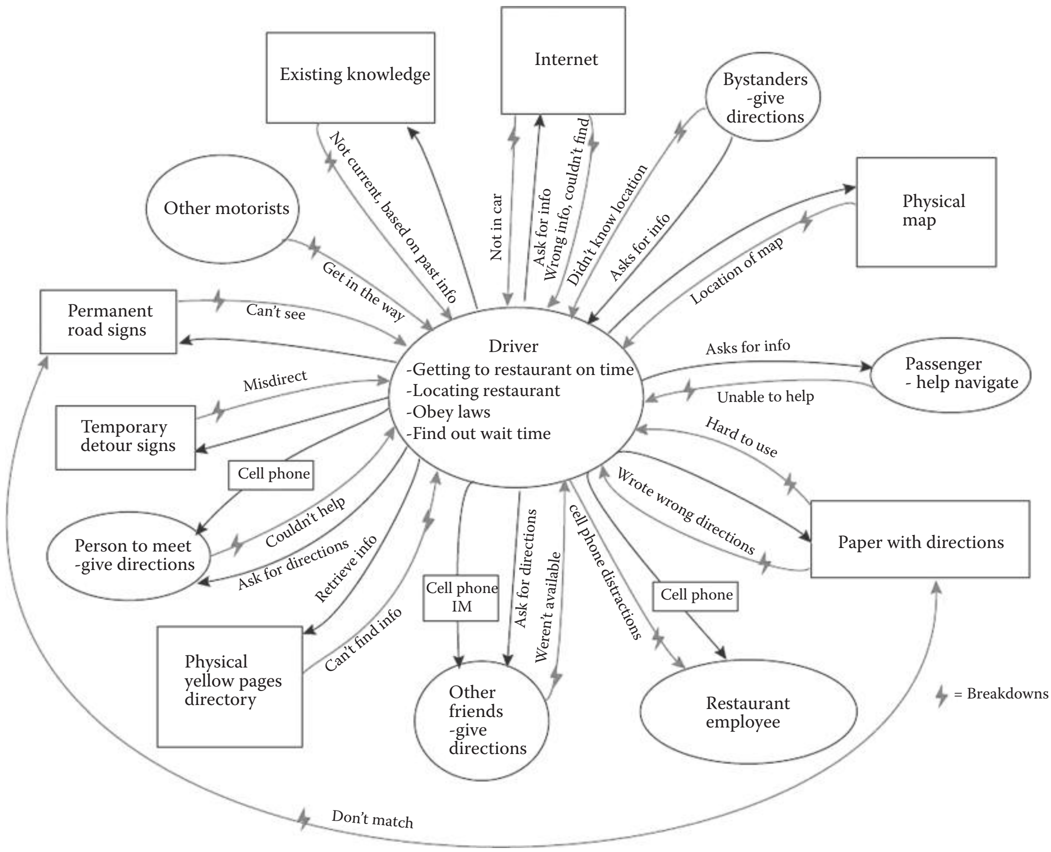


FIGURE 1.3 A sample flow model for a driver during a navigation task.

Annotate each part of the artifact with its purpose or how it supports its purpose. If there are parts of the artifact that interfere with or do not support the participant's tasks, mark them with a red lightning bolt with a short phrase indicating the problem. When this model is complete, you will have a visual representation of what information is important to the participant and what parts of the artifact supported the tasks (Beyer and Holtzblatt 1998). Figure 1.5 shows part of an example artifact model for an email application.

1.2.2.1.5.4 Cultural Model A cultural model provides a tangible representation for the culture that often influences your participants. It shows the people, organizations, and groups that influence each other in the participant's culture. To begin this model, draw a circle in the middle of the workspace and label it with the participant number (e.g., "User 1"). Put their role in parentheses below

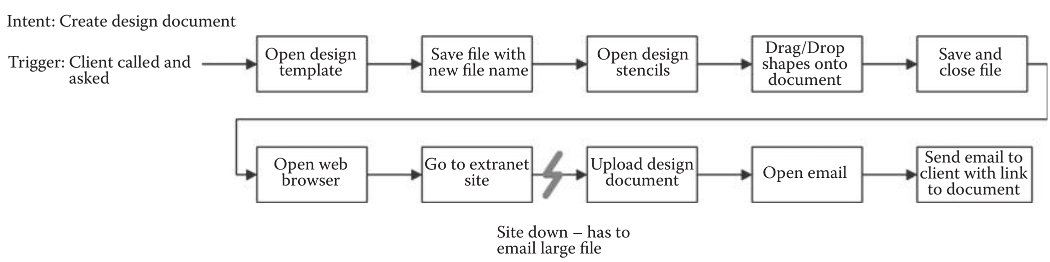


FIGURE 1.4 The start of a sample sequence model for creating a document for a client.

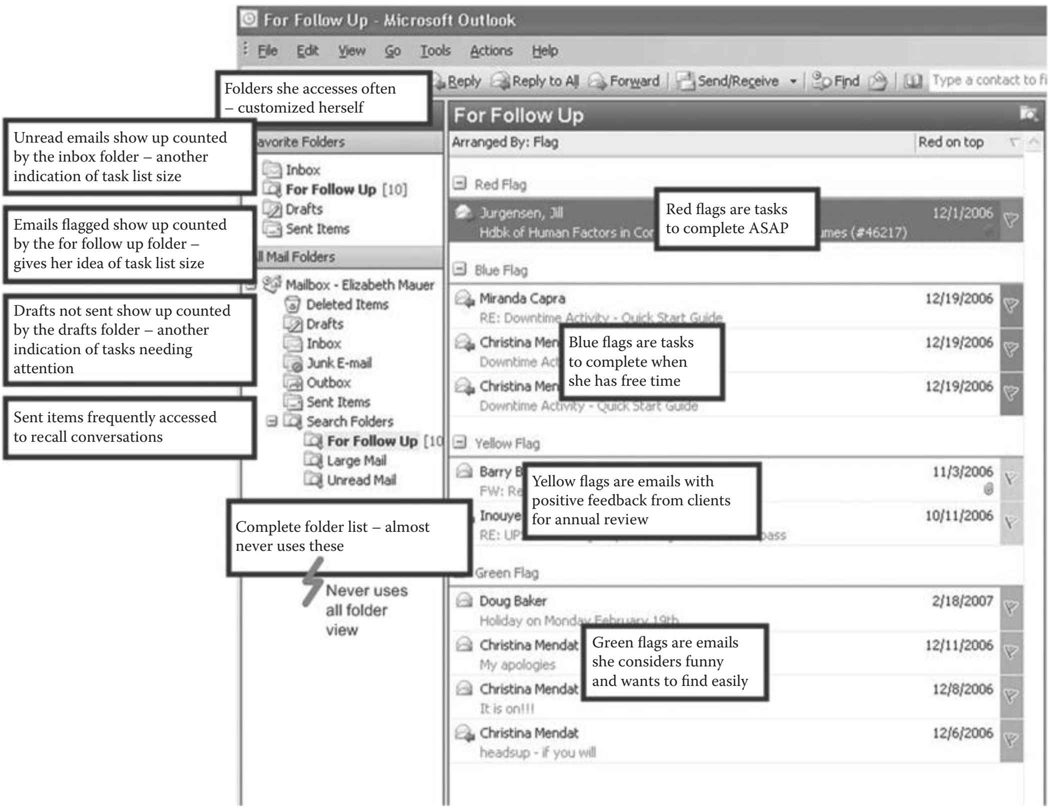


FIGURE 1.5 Part of an artifact model for an email application.

the number. For each influencer of the participant, draw a circle behind the participant's circle. The size of the circle can be proportionate to the amount of influence that entity has over the participant. Represent the influences between the circles using arrows with a short phrase indicating the type of influence. If an influence interferes with or does not support the participant's tasks, mark it with a red lightning bolt with a short phrase indicating the problem. When this model is complete, you will have a visual representation of the cultural context of the participant's work place (Beyer and Holtzblatt 1998). Figure 1.6 shows the start of a sample cultural model for an employee at a consulting company.

1.2.2.1.5.5 Physical Model A physical model visually depicts how physical space affects the participant's tasks. To create one, start by drawing the participant's workspace. As you move through the transcript, add in the items that affect the participant's work, such as telephones, file cabinets, printers, etc. Annotate the drawing with the movement of the artifacts and the participant using arrows. If there are parts of the space that interfere with or do not support the participant's tasks, mark them with a red lightning bolt with a short phrase indicating the problem. When this model is complete, you will have a visual representation of the participant's workspace and how that workspace affects their tasks (Beyer and Holtzblatt 1998). Figure 1.7 shows the beginning of a physical model for an office environment.

1.2.2.1.6 Group Photos into a Photo Collage

If you took photos during your sessions, this is a great opportunity to create a photo collage. Start by laying your photos on a large work surface. Begin by grouping the photos by topic. For example,

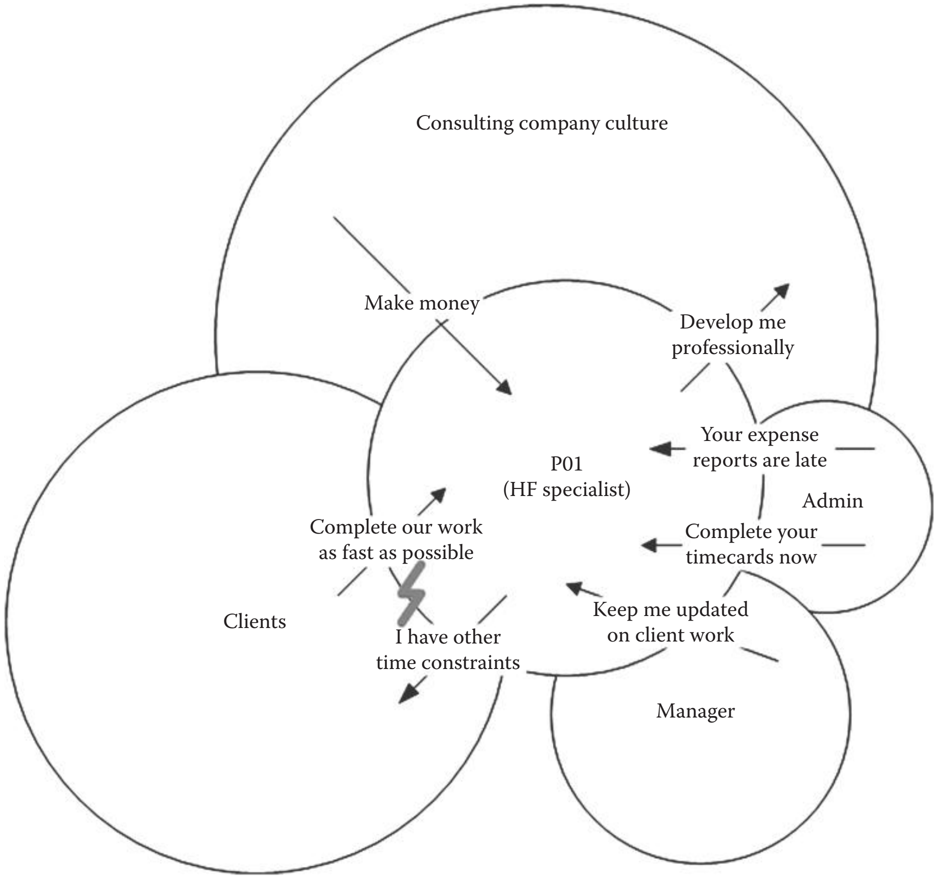


FIGURE 1.6 The start of a sample cultural model for an employee at a consulting company.

place all photos of the same artifact together, or place all photos of awkward wrist positions together. If a photo needs to be in more than one group, make a copy of it. Don't put too much thought into the groups at this point; you'll analyze more in a later stage. Label each group and pin the groups onto the wall or a piece of foam core board for display. These groups will become focus points for later stages of analysis and design.

1.2.2.1.7 Code Session Videos for Important Events

If you recorded your sessions using a program that allows for video coding, you can watch each session video and flag certain events that you consider important for later analysis. Watching the session videos is probably the most arduous and time-consuming task of the ones discussed here. However, it can provide a wealth of information for later stages if you have the time and money to do it. Programs such as Morae® allow you to flag an event in a video and add comments to it, score it, or a number of other things. It is also convenient if you would like to make a highlight video of all the important events to show the design team, your client, or other stakeholders.

1.2.2.2 Output of this Stage

When you are done organizing your data, you should have several different artifacts that identify the common themes and focus points you will need for stage 3—interpreting the data.

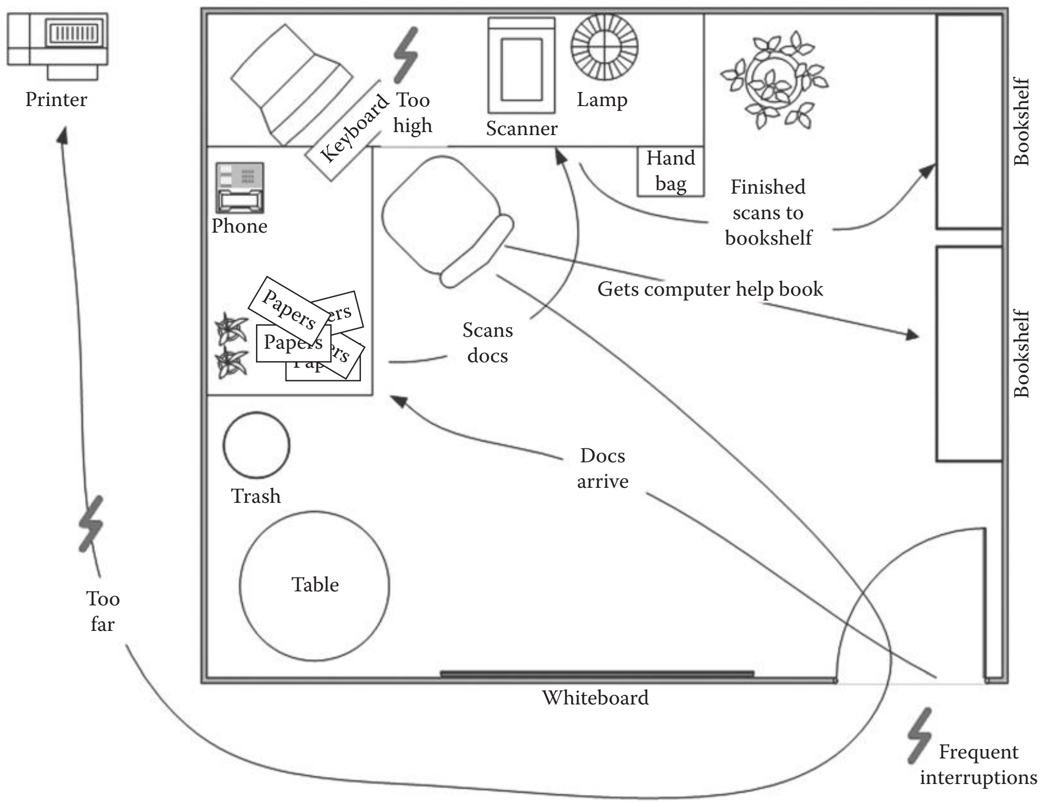


FIGURE 1.7 A sample physical model for an office environment.

1.2.3 Stage 3: Interpret the Data

The ability to interpret data may not be as simple and straightforward as it sounds. Assuming that your data are clean, relatively reliable and have been intelligently organized (stage 2!), the next logical step is to analyze the data. There are some obvious analyses that have to take place, such as the descriptive information from the sample that you studied. This section will present some common ways to gain control of the data and to start ideating product innovations based on gaps and overlaps.

1.2.3.1 Generate a Written Overview of the Research

For your benefit and that of your team, create a written, yet brief overview of your design research. This should be very simply stated and will help as you dive into your data. Clients and managers will want to know who was involved, what topics were covered, and when to expect the results. Often, months can lapse between establishing those goals and reporting the results. Our suggestion, therefore, is to write a concise demographic breakdown of the context of your research and the overarching goals that were earlier established; and do this even before you start to analyze your results. All it takes is about one hour of your time. For example:

> Observational research of 30 printer owners derived from our four user categories was conducted in May 2007 with the following goals: to make updates to our existing persona profiles and to generate a catalogue of usage models, from the most basic to the unpredictable ways in which our printers are used. A final report of the research will be presented in June.

A brief statement such as this will help to make it well known to others around you what you did and why you did it. Think of it as proactively reinforcing your research so that when it is finalized and reported, there are minimal surprises.

1.2.3.2 Know Your Sample

Next, truly know your sample and report on who participated in the research (as opposed to who the research was supposed to target). Sounds simple, right? To the researchers and the people out in the field, this is simple. But as we all know, sometimes the people we want to study are not available. Sometimes they do not exist. And other times, they are all-too-well studied and nothing further is learned. At this point, outlining the research participants will further connect your audience to the conclusions that can and should be drawn. Can some research findings be easily extended to other user groups? Sometimes, but not always, and being clear in that distinction will only help to promote the realities of your research. Research is never perfect, but hiding this is to be avoided at all costs. For example:

Of the 30 observational research sessions that were conducted,

- Seven were small business owners (under 50 employees)
- Seven were medium-sized business owners (50–500 employees)
- 10 were large business owners (over 500 employees)
- Three were from state government organizations
- Three were from federal government organizations

Create a visual representation or diagram the research sample. Graphics can be great for leaving a lasting impression of the participants, long after the audience has put down your report. Figure 1.8 shows an example of this.

Next, create obvious and logical connections between the demographic profiles that are represented in your sample and the goals of the research. This will remind the reader why the participants were chosen and, more importantly, what types of users should have been included, but maybe were not able to be included for various reasons. Highlight this point, if it needs to be made, immediately at the beginning of the work, so that the audience is clear from the start if the research has some inherent limitations. In other words, setting the stage for your reader about the amount of generalization that is appropriate to make, based on the research and the sample, can easily mitigate problems of misinterpretation by your readers, bosses, managers, and clients later on. Everyone knows that in research the best-laid plans sometimes unravel, yet the show must go on. What we learned in school regarding ideal sample sizes, depth and breadth of research, often must be adapted to fit within the very real deadlines of the product development world.

1.2.3.3 Find Common Themes

After taking the time to tie the research sample to the goals of the research, the next and most important step is to find common themes in the data you gathered. You started this process in stage 2 by identifying key focus points for analysis. Now you need to find the common themes among them and start creating a story. This is the information that will either confirm or deny existing suspicions and can help to trigger new ideas. It will also show the sponsors of your research how well organized, thorough, and interesting the research results can be when applied to their own goals. But how do you find these commonalities? Take the time to look back through your artifacts from stage 2—documents, diagrams, work models, collages, and videos. Re-read what you gathered in a single

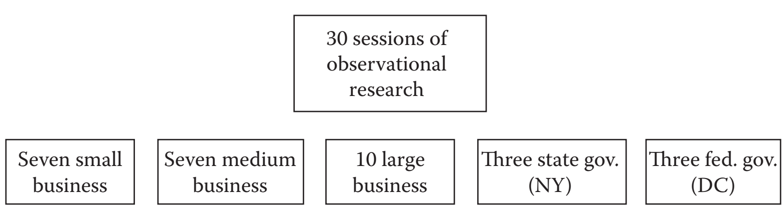


FIGURE 1.8 A graphical representation of a research sample.

sitting, and immerse yourself in the data. Force yourself, even if you were the primary researcher on the project and moderated every single research session, to sit down with the large amount of data you gathered and review it. You can do this over the course of several days. Do this even if you feel like you know everything that you saw, because it is almost guaranteed that you know less than you think you do, even when you are the one absorbing all the information. Take time out of your project schedule to simply sit with the data, reviewing notes, artifacts, and the like, tying things together and jotting down common themes that start to emerge. It is all too common and easy for even the savviest and most experienced researchers to come back from collecting data in the field, feeling as if they know every angle from every session; they have solved the problems, answered the questions, and invented new products that will revolutionize the industry. Unfortunately, this is rarely the case, and is more an effect of being on a "research high" than being grounded in reality. To find common themes that truly emerge in your research, it must be a theme. A theme with one data point is not a theme, it is an anomaly. Anomalies are important to the research, especially when they trigger new thinking or challenge existing concepts. But a true theme is something *common* that is connected with converging evidence.

Once you have reviewed all your data, descriptive statistics and frequency counts are the next most likely analytic technique that will help to weave a story. These are the common, big bullets that we see in the all-too-familiar PowerPoint presentations of research findings. They are the necessary and logical threads that start to tell your story. For example:

> All large business owners ($n = 7$) reported a very similar workflow and printing process as did the three users in state government and the seven small business users.

As a reader of a big statement like this, the researcher must be prepared with the supporting evidence. Someone will absolutely think to themselves, "Okay, that is an interesting finding. Can you show me how you arrived at this conclusion based on only seven people?"

All the statements should be reinforced with data and diagrams of those data. It will help to reinforce the validity and perceived impact of big statements. You want your reader to feel confident that the researchers are not reporting findings that are supported by only one or two corner cases and those potentially large conclusions are not being errantly drawn. Show the reader evidence by pointing out the workflow that was noted from all the sessions that are implicated in your conclusion. A workflow diagram of the process, giving names to the steps, will show visually and very nicely, how workflows are similar among these sub-groups.

Why are we suggesting this technique? While some of the clear-cut research results are being reported, you will actually start to incubate new ideas, revised ideas, and the applicability of any product idea. You are becoming your user, as much as is reasonably possible. In this way, you are not only the voice of the user, but also the factory of potential new ideas—whether or not the ideas have come to you so far.

1.2.3.3.1 Comment Analysis

A great technique for further identifying with your user is to conduct a comment analysis. Whether it is formal or casual, the verbal comments captured in the field will be organized into a series of common themes. Catalogue these into general categories and create new ones as necessary. Don't paraphrase; doing this with verbatim quotations will help you stay true to the participants' message. The underlying message or a gap in participants' needs will present itself clearly through a comment analysis.

1.2.3.3.2 Statistical Analyses for Data Interpretation

Test statistics can be the design researcher's best friend and worst enemy all at the same time. We are well aware of the potential ways—conscious or subconscious—in which people can be misled with statistics, due in large part to the apparent weight with which analyses are often presented.

In design research efforts, where the goal is to study a usage environment, observe and note the user's needs, surroundings, frustrations, and other key information, applying statistical analyses should be only one of many ways in which data are interpreted. Common themes, user comments, problems, and the frequency with which these factors occur in the field are the important conclusions from the design research. Submitting those data to Chi-squared analyses, paired-comparisons (such as *t*-tests or non-parametric comparisons) will help drive home the impact of the findings. However, it should be noted that applying statistical tests to field data, which can be non-normalized, can lead to results that are prone to misinterpretation. What does that mean? Let's say that four of the eight participants from one sub-group were found to be "unhappy" with their current printing solution and two of five users in another sub-group were found to be "unhappy." What can be done with those data? It could be tempting to want to do more with those numbers—"let me submit that to a *t*-test and see if two is different from four." Anything can be tested with a test statistic, yet the question to ask is whether the data are appropriate for the statistic you choose. Subjective, qualitative data lend themselves nicely to statistics that compute the difference or trend in scalar data. These are great ways to use statistics in the design research process. A significant result in the comparison of two sets of survey data that is further supported by other findings is even more impressive. However, spending time looking to further an argument for argument's sake can be a time-waster in the face of the new product development process. Remember that the ultimate goal here is to find those "aha" moments and revelations and sparks of genius that will lead to new and interesting twists on a product. It is our experience that statistics have a well-founded and important place in the researcher's toolbox, and traditionally, we love applying statistics to data sets, but staying focused on reading between the lines, connecting the dots, studying the diagrams, and continuously incubating the ultimate goal will lead to more interesting results.

1.2.3.4 New Idea Generation: Where Does It Come From? Is it Hiding Under a Rock?

So far, you have done a great job conducting your research, piloting the data analysis, and going back when necessary to further examine possible information, yet you feel stuck. Your manager or client gave you a huge task and responsibility of helping the company further its profits. You feel it is your task to create compelling products and to redefine the company's product lines. That's quite a task. Remind yourself and others around you that the point in doing the research is to place some concrete boundaries and real intelligence around the problem space. After that goal is accomplished, it is often the case that million-dollar ideas emerge—purely by happenstance—that will become the catalyst for new products for your company. Sounds exciting, right? The point is to be cautious—know your research and know your user. Overstating or even exaggerating a point that is not grounded in the research findings can lead teams down the wrong path, or, worse—it can lead to people becoming distrustful of the research.

The main output from this stage will be a connection of the goals of the research to the findings. This is perhaps one of the most important steps. The sponsor of the research will have the results of what was promised and what was expected. The research has led to two main things: (1) the documented output of the data, which includes diagrams, photos, themes, and outlying pieces of information; and (2) the researcher's internal working knowledge of what happened. These memories and the solidification of the story that can be told will live with the researchers throughout the next phases—the generation of new ideas. Therefore, it is imperative to stay close to the research as you move forward.

1.2.4 Stage 4: Apply the Research to Design

The research has been completed and the documentation is finalized. You have video recordings, top-line reports, posters hanging in your hallways and, at times, revised mission statements all due to the findings in the research. An important next step is to do something with these data. But what?

Our suggestion at this point is to create a small, cross-functional team comprised of graphic and industrial designers, design researchers, human factors and usability engineers, and marketing representatives. The team does not need to be large and this step does not need to take large amounts of time or money. Yet the overarching benefit will quickly become obvious.

Define the team and agree to spend a few half-day sessions working together on a clearly defined purpose—to brainstorm new product ideas. The researcher should present the research to the team. The marketing participant should summarize the goals and pressures inside the company in clear-cut terms. The designers will add the creative and innovative skills beyond compare to help in this process. The team should begin by generating a mind map or concept map of a new product idea. This can be started simply with a central idea—perhaps an idea that came from top management or a team member or a participant. Ideally, it is supported by the research. This idea is written down (on paper, on whiteboard, or anywhere easily visible) and all team members quickly go around the idea with new ways to think about accomplishing it.

For example: A wildly popular new product idea that came from your data is a carrying bag for personal printers. Some in the company believe that such a carrying bag will be the wave of the future for your printer company. Even if there is a lack of agreement about this, the idea is valid and deserves consideration. One very easy technique for studying this idea is to create a mind map of the carrying bag and have the team ideate on ways in which the carrying bag would work. Write down functional uses for the bag next and allow others on the team to further that concept. Examples include environmental uses for the carrying bag and other user profiles that need a carrying bag—whether they know it or not. Further the concept by thinking about the physical forms and shapes the bag could have. From what materials will the bag be made? The idea needs time to breathe and to live on its own. Test its validity inside your cross-functional team and try to make a case for the idea (no pun intended). Figure 1.9 shows the beginning of a mind map for the printer carrying case.

At this point, you and your team can continue this process until there is a high level of agreement on the most viable new product concepts or tweaks. These concepts should be presented to other stakeholders for further review and refinement. Feasibility studies can be conducted, and prototypes

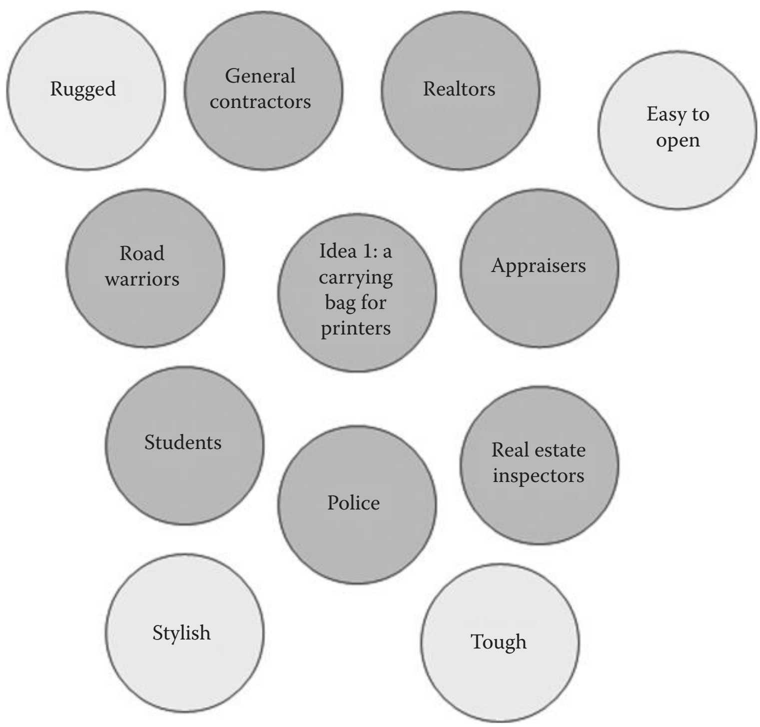


FIGURE 1.9 The start of a mind map for a printer carrying case.

can be created for further study. At this point, you would find yourself back at stage 1, ready to define clear goals for a new research project. Lather, rinse, repeat—and most of all, have fun!

ACKNOWLEDGMENT

We thank Jessica Phipps for her thoughtful comments and editing.

REFERENCE

Beyer, H., and Holtzblatt, K. 1998. *Contextual Design*: *Defining Customer-Centered Systems*. San Francisco: Morgan Kaufmann.

2 Manufacturing Attractive Products Logically by Using Human Design Technology: A Case of Japanese Methodology

Toshiki Yamaoka

CONTENTS

2.1 INTRODUCTION

The fundamental trend in product development has shifted from conventional development, which stresses hardware-related requirements, to one that is oriented to users' requirements. The latter style of developing products is based on user needs. The background to the increasing prevalence of this style includes the fact that differences in technology have narrowed among manufacturers in the fields of household electrical products and electronic appliances, and social circumstances have made it more compelling to regard user requirements as important (e.g., ISO 13407). In addition, some harmful effects have been pointed out; because business has been subdivided at a primary stage in product development, the person in charge often puts forth his/her efforts only in his/her territory and fails to take an overall perspective. In order to cope with these circumstances, a new method of developing products has been devised, called human design technology (HDT).

HDT is a design technology that synthesizes marketing research, ergonomics, cognitive science, industrial design, usability evaluation, and statistics (multiple valuable analysis), and forms appealing products that are friendly to humans (Yamaoka 2001). In other words, this technology is defined as one that requires scientific analysis and various types of human-related information (physiology, psychology, cognition, behavior, etc.) as necessary design conditions. The method is aimed at reconsidering the conventional process, which relies on intuition throughout the stages of planning, designing, and evaluation, to achieve a process that employs the viewpoints of analysis and quantification to the highest possible degree, in order to manufacture reliable products that are based on user needs while incorporating all necessary design conditions.

2.2 PROCESS OF DESIGN DEVELOPMENT

The following describes the HDT process (Figure 2.1):

1. Gathering user requirements: extracting the problems and needs for products.
2. Grasping current circumstances: researching the users' response to the target product in the market.
3. Formulating product concepts: formulating a concept on the basis of information such as user needs.
4. Designing (synthesizing): visualizing the product on the basis of the concept.
5. Evaluating the design: evaluating the visualized design.
6. Surveying the actual usage conditions: surveying the users' attitude toward the product after it is sold, and use the survey results as needs for developing subsequent new products.

The examination of HDT ranges from gathering and analyzing users' needs, formulating the product concept, materializing and evaluating the design, and surveying the actual usage conditions for products bought by users. Basically, a process was conceptualized to visualize and evaluate the requirements on the user side, and also to examine the requirements on the hardware side as necessary. The methods for each step are described below, and a tube file is described as an example at the end of this report.

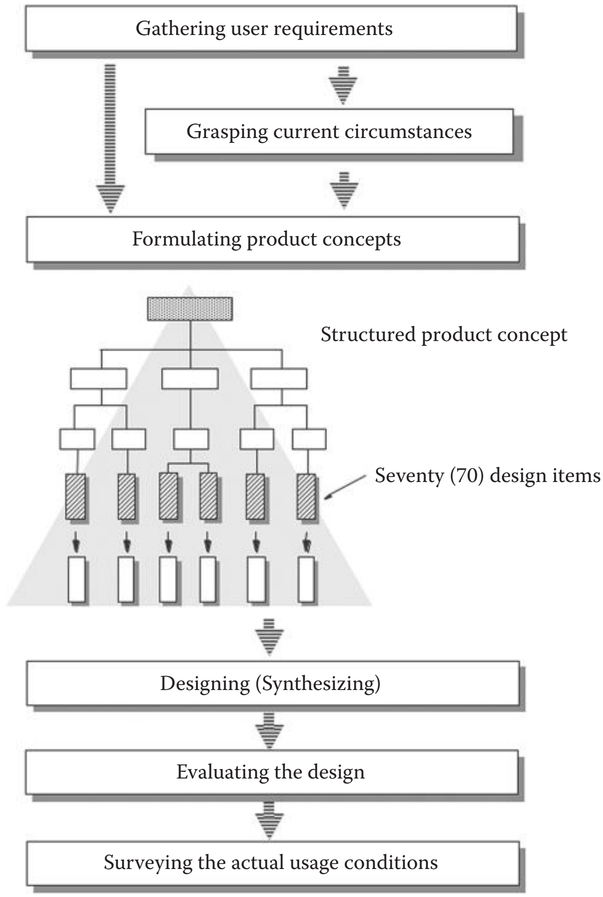


FIGURE 2.1 The process of HDT.

2.3 GATHERING USER REQUIREMENTS

This is the first step in extracting user needs, using methods such as three-point (3P) task analysis, direct observation, and an evaluation grid. In HDT, 3P task analysis and direct observation are regarded as especially important, because potential user needs are obtained with these methods by analyzing the users' unconscious actions. Also, 3P task analysis, which does not require any users, is a beneficial approach in terms of cost.

2.3.1 Direct Observation Method

There are two kinds of observation methods: direct and indirect. The direct observation method is as follows.

1. Observe things as they are.
2. Observe things under a certain condition; observe the change after adding some mechanism into human machine interface (HMI).

The indirect observation method means that the users' actions are sought indirectly using a sensor. This is called in-situ ergonomics (Shinya and Yamaoka 2005). However, the observation method that is frequently used is the direct observation method. The actual direct observation methods are "direct observation to observe things as they are" and "direct observation to observe things under certain conditions."

2.3.1.1 Direct Observation to Observe Things as They Are

It is easy to extract problems by observing things as they are at first, and then to analyze them from the following viewpoints.

2.3.1.1.1 Extract Problems from the Viewpoints of Five Human Machine Interface Aspects

In HMI examination, extract interface problems from these aspects: physical, information, temporal, environmental, and organizational.

1. Physical aspect: Search physical problems through the following three points:
   a. Check the user's posture (positioning)
   b. Check the operational direction and strength of the controls (dynamic aspect)
   c. Check the fit between the controls and the user's body (especially hands) (contact surface)
2. Information aspect: Exchange information between the system and users, and search problems from the following viewpoints:
   a. User's mental model
   b. Easy to understand
   c. Easy to see
3. Temporal aspect: search problems from the working/operating viewpoint.
4. Environmental aspect: search problems from the viewpoints of lighting, air conditioning, noise, and vibration.
5. Organizational aspect: search problems from the viewpoint of HMI management, such as maintenance, information flow in an organization, and human relationships.

2.3.1.1.2 Search Traces

Correspondence between the system and users leaves traces. Finding the traces left by users will extract problems. For example, in a case where the door handle of a toilet is not used and the door is pushed with the hand(s), such an action will make the door paint come off and leave traces (Figure 2.2).

FIGURE 2.2 The traces on the door.

2.3.1.1.3 Observe the Clues for Operation and Action

When we start to act, we need some clues to show us the viewpoints from which the problems are to be extracted.

2.3.1.1.4 Observe the Flow of Operation and Action

Operational flow can extract problems by link analysis.

2.3.1.1.5 Research the Restricted Circumstances for User Operation and Action from the System Side

By researching the circumstances restricted by the system for operation and action, such as limited operation at the coin inlet of a ticket-vending machine, various problems can be extracted.

2.3.1.2 Direct Observation to Observe Things Under Certain Conditions

If it is difficult to grasp HMI and extract the problems through only direct observation, a single-case experimental design (Iwamoto and Kawamata 1990) is used for extraction. In this method, the difference and effect by treatment, before and after, are interpreted by picking up a single case and comparing the results through the following procedure: A (baseline, non-treatment)→B (treatment)→A (baseline, non-treatment)→B (treatment). For example, using this single-case experimental design, variations in the way students place their shoes on a mat in front of a laboratory were researched, after changing the mat size from the conventional small size to a large size. This method made it possible to successfully extract a lot of requirements concerning the mat.

2.3.2 Three-Point Task Analysis Method

Task analysis is a method for extracting problems in the tasks of various scenes where a user uses an appliance. In order to prevent a lack of evaluation for task analysis in different states and to evaluate from the user's viewpoint, a means was contrived to extract the problems by dividing user information processing levels into three steps: acquire information→understand/judge→operate. This is the 3P task analysis method (Yamaoka 2002), in which a column was added to the right end, so that the problems extracted in each task will lead to constructing a product concept, and to make them into requirements to be presently solved, while the current method is up to the step of extracting problems. The column is divided into two parts: one is for writing in items to be solved actually and instantly, and the other is for items that are expected to be put into practice in the near future, though it would be technically difficult now. The latter items in the column can be used again. And, seven clues were prepared to think out the solutions (Figure 2.3).

This method can be conducted both with and without examinees. However, the method using examinees is superior to the other in grasping various circumstances, even though it is costly.

2.3.2.1 Acquire Information

In this step, information is acquired by the user. It is equivalent to the human sensation/perception level for processing information. The main point is how easy it is to get information. In this step, mainly for electrical appliances, problems can be efficiently extracted from the following viewpoints: (1) optimal layout, (2) ease of seeing, (3) emphasis, (4) clues/necessary information, and (5) mapping.

2.3.2.2 Understand/Judge

In this step, perceptional information is cognitively processed. It is the level for understanding/judging the information. Mainly for electrical appliances, this step allows problems to be efficiently extracted from the following viewpoints: (1) unclear meaning, (2) affordance, (3) vagueness, (4) feedback, (5) operational procedure, (6) consistency, and (7) mental model.

Scene:					
Task (+subtask)	Pick up problems in "information acquisition → understanding/Judgement → operation" process			Solution (Requirement) Seven cues (1) Examine the product's attribute (2) Change system (3) Make proposals for living (4) Think from the viewpoints of PL and human error. (5) Think from the viewpoints of ergonomics and universal design (6) Think on the basis of environment	
	Information acquirement	Understanding and judgement	Operation		
	-Take account of: (1) The best suited layout (2) Easy to see (3) Emphasis (4) Clues/necessary information (5) Mapping.	-Take account of: (1) Unclear meaning (2) Affordance (3) Vagueness (4) Feedback (5) Operational procedures (6) Consistency	-Take account of: (1) Incompatibility with physical characteristics (2) Trouble		
				At the present	In the near future
Task 1					
Task 2					

FIGURE 2.3 The format of three-point task analysis.

2.3.2.3 Operate

In this step, human intention is transmitted to the machine/system. The judged information is given as an instruction to the machine by using human hands and legs. This step allows problems to be extracted from the following viewpoints: (1) incompatibility with physical characteristics (posture, fit, and torque [the necessary force to operate] are especially important for operation) and (2) troublesomeness.

2.3.3 Three-Point Task Analysis Procedure

The following is the 3P task analysis procedure:

1. Specify typical scenes where the products concerned are to be used; think of five or six typical scenes where the products to be examined are to be used.
2. Specify the common task flow at these scenes; list the tasks done in each scene in order.
3. Refer to the clues in each step and extract the problems through them.
4. Think of the requirements for the problems that were finally extracted, using the seven clues listed below. Record the designed requirements with memos and illustrations in the right column, as requirements for the present or in the near future.

The seven clues are as follows:

1. Examine the product's attributes; to change its structure, material, and way of use.
2. Change the system.
3. Make lifestyle proposals.
4. Think from the viewpoints of product liability (PL) and human error.

5. Think from the viewpoints of ergonomics and universal design (design for all).
6. Think from the aspect of the environment.
7. Conceive an idea by comparison; create new ideas by comparing the same or different kinds of products.

2.4 GRASPING THE CURRENT CIRCUMSTANCES

This step confirms how the products are presently perceived by users in the market. The results of this step are to be acknowledged and examined in order to take countermeasures. The method mainly utilized here is the correspondence analysis method, which is simple to use. It uses approaches such as showing a relationship diagram for unclear information (e.g., keeping related information near to each other). The frequency of evaluation keywords (e.g., luxurious, modern) are examined by questionnaires to determine the degree to which they are applied to the product group to be researched. The outcome of the questionnaires is presented on a two-dimensional display. The products and keywords are positioned near each other on the same side when there is a close relation between the two. The direction and length from the origin are used for examination. In other words, when competition is to be avoided, it is decided whether the territory where those products are not positioned should be targeted, or whether to risk competing in the same territory with them (Figure 2.4).

2.5 FORMULATING A PRODUCT CONCEPT

2.5.1 Constructing the Structured Product Concept

The concept is structured in order to strive for logical consistency among the concept items and to prevent a lack of items. In addition, the importance of the upper items of the product concept is ranked based either on the planner's idea or on the outcome of user questionnaires. These importance values are also regarded as comparison values for production cost. If the cost is unacceptable, the lower items, i.e., those of less importance, can be cut. Apply the lowest items of the structured concept to the 70 design items listed below to complete the product concept (Figure 2.5).

	a	b	c	d
X	10	8	2	3
Y	2	4	7	4
Z	3	1	3	9

(Figures in the table mean frequency.)

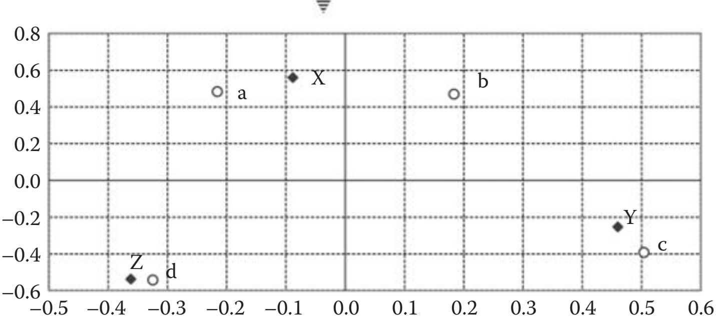


FIGURE 2.4 The correspondence analysis process.

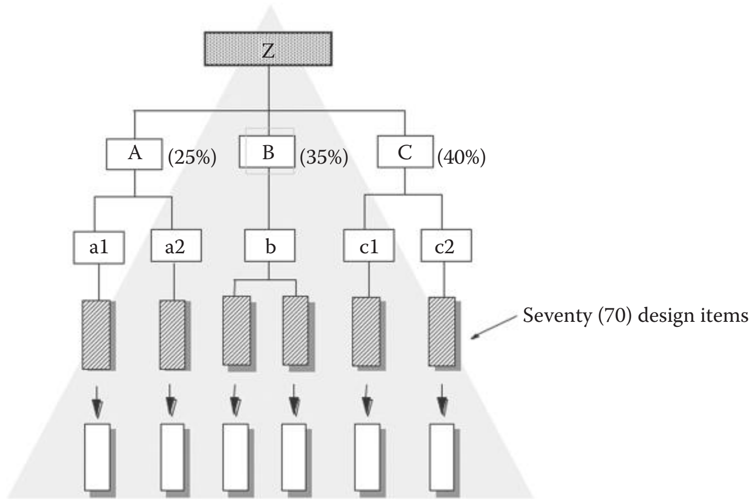


FIGURE 2.5 Structured product concept.

2.5.2 Constructing the Product Concept with a Bottom-Up Style

Convert the problems and needs acquired by gathering user needs into user requirements, and stratify those that are classified to have the same function. If new upper items are found from the structural context of the upper items and the topmost items, add them. These requirement items were originally derived from problems. In case items with sufficiently necessary product conditions are lacking, or in case the planner wants to add an item, these may also be added as the need arises (Figure 2.6).

2.5.3 Constructing the Product Concept with a Top-Down Style

If the image of the product that the planner wants to develop is clear, it can be materialized by determining the top concept items. These items can be further broken down into lower items to construct the structured concept.

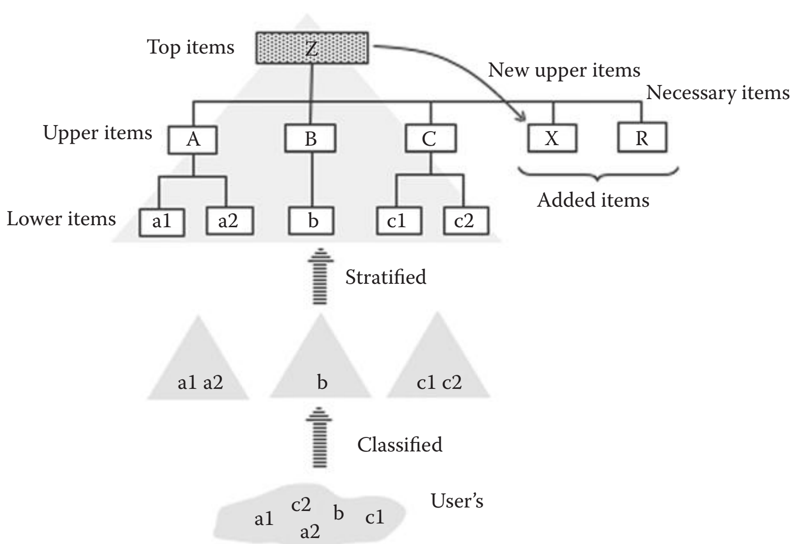


FIGURE 2.6 Constructing the product design concept with a bottom-up style.

2.5.4 Creating Specifications

At this stage of concept construction, the system's outline has become clearer. Create specifications related to users and make each one precise. Establish the objective of the system, decide the role between the user and the system, and clarify the target users' attributes.

2.5.5 Seventy Design Items

The design items are positioned at the bottom of the product concept, and are referred for the purpose of visualizing. These 70 items are not always applicable to all products, but they are fundamental and essential, and are subdivided into eight larger items as follows:

1. Oriented toward interface and usability→user interface design items (29 items)
2. Friendly to the aged and the disabled→universal design items (Nine items)
3. Oriented toward product benefit and sensitivity→sensitivity-conscious design items (Five items)
4. Oriented toward safety→PL design items (Six items)
5. Oriented toward robustness→robust design items (Five items)
6. Oriented toward maintenance→maintenance items (Two items)
7. Oriented toward the global environment→ecological design items (Five items)
8. Others→five HMI aspects and others (Five items)

These eight essential items cover the major ones to be examined. The details are as follows.

2.5.5.1 User Interface Design Items (29 Items)

2.5.5.1.1 Construction of a User-Friendly User Interface System

1. Receptivity/flexibility: flexibly compatible appliances according to user levels of knowledge, experience, skill, and taste.
2. Customization depending on different user skill levels.
3. User protection: protecting the user from physical harm.
4. Universal design: providing an interface that the disabled and the aged, as well as the healthy, can operate with equal ease.
5. Application to different cultures: considering the cultural background of the target users, such as language, social customs, and religion.

2.5.5.1.2 Arousing the User's Motivation

6. Providing users with enjoyment: providing enjoyment so that users can actively take part in operating and want to use more.
7. Providing users with a feeling of accomplishment: providing joy so that users can operate skillfully and want to use more.
8. Securing the user's leadership: making it possible for users to operate freely as intended from the beginning of the operation to the end.
9. Mutual trust: maintaining a relationship of mutual trust with the user.

2.5.5.1.3 Construction of Effective Interaction

Acquiring effective information:

10. Clue: giving clues for operating or thinking, when the user operates the appliance for the first time or forgets how to operate it.
11. Simplicity: making the display presentation and operating procedure simple and neat.
12. Easy information retrieval: making it easy to retrieve certain information.

13. At-a-glance interface: presenting the number and kind of available functions, the entire amount of operations, and the working range and presentation content, so that they can be grasped entirely.
14. Mapping: clarifying the relationships among the elements of information and also those between the human and the appliance.
15. Distinguishability: making it easy to distinguish the differences between the kind and quality of information.

Making it easy to understand and judge:

16. Consistency: unifying the structures and operating procedures related to information indication, layout, and terms.
17. Mental model: taking account of the user's system image and operational concept of the appliance.
18. Providing multilateral information: providing users with multilateral information to help them judge the situation.
19. Appropriate terminology/messages: using terminology/messages that suit the user's comprehension level.
20. Minimizing the user's memorizing load: minimizing the burden on the user's memory.

Comfortable operation:

21. Minimizing the user's physical load: lightening the user's physical discomfort and fatigue and not applying any physical strain, even unconsciously.
22. Operational response: getting the right response from the system while operating, and not feeling that something is wrong.
23. Efficiency of operation: reducing the user's workload by automating procedures and minimizing input operation.

2.5.5.1.4 Common Keywords

24. Emphasis: emphasizing important information to help users to understand it instantly.
25. Affordance: designing with the aim of inducing human behavior.
26. Metaphor use: facilitating users' understanding by using metaphors based on their culture, experience, and daily-life knowledge.
27. System structure: showing system structure to help users understand the meaning of the operation.
28. Feedback: responding to users from the system side.
29. Help.

2.5.5.2 Universal Design Items (Nine Items)

1. Adjustability: making it applicable to various users, including the disabled, by adjusting the appliance side.
2. Redundancy: this refers to preparing several alternatives for interface input and output.
3. At-a-glance understanding of functions and features: this refers to improving the clarity of the interface.
4. Feedback: responding to users from the system side.
5. Error tolerance: the ability of the machine to somehow cope when the user makes an error.
6. Acquisition of information: making it possible to check for information, basically through clues and distinguishability, and from a multi-modal viewpoint, including the senses of hearing and touch as well as sight. For example, for the visually disabled, controls that have a tactile bulge at places that are important for operation as a clue, or which show the degree of operation (e.g., slide-style switches and rotary knobs) are recommended.

   a. Sense of sight: easy to see (make characters large, provide high contrast, and avoid sudden shifts in the line of sight).
   b. Sense of hearing: easy to hear and listen to.
   c. Sense of touch: tactile clues.
   d. Physical aspect: comfortable posture.
   e. Environmental aspect: optimal illumination intensity, no glare, air conditioned, etc.
7. Understanding and judging information: here, this refers to common measures of facilitating understanding.
   a. Presenting individual pieces of information, with only one task in each presentation.
   b. Making use of symbols, such as icons, as clues.
   c. Reducing the burden of memorizing by using metaphors and analogies.
   d. Making selections by "recognition" (e.g., selecting from menus), rather than "recall" (e.g., with memorized rules).
8. Operation.
   a. Comfortable posture: avoid forced postures.
   b. Fitness: fitting nicely with operating devices, tools.
   c. Operational force: operable with only slight strength.
   d. Operating method:
      i. Easily operable with one action, i.e., not having two concurrent motions or subtle operations.
      ii. Operable with one hand.
      iii. Using familiar methods.
   e. Environmental aspect: optimal illumination intensity, no glare, air conditioned, etc.
9. Continuity of information and operation. The flow of information and operation must be uninterrupted; provide a smooth flow for each step: acquire information→understand/judge→operate. This item was extracted because the viewpoint of solving problems based on the task flow is often missing, while solving universal design problems at the easily visible subtask level is encouraged. For example, even though an elevator for wheelchair users is provided in a train station, other stairs often remain before reaching that location, which makes it difficult for wheelchair users to use the elevator.

2.5.5.3 Kansei (Sensitivity) Design Items (Nine Items)

1. Design image: modern, nostalgic, stylish.
2. Color: having a sense of security, novel.
3. Fit: a sense of unity between a human and an appliance; a fitting shape, a feeling like envelopment.
4. Shape: a simple form, a stylish form.
5. Functional ability/convenience: with good function, easy to use.
6. Ambience: a tasteful interior, a calm atmosphere.
7. New combinations: effects from combinations of images and music, and harmony with different genres.
8. Feel of material: material with a feeling of richness, new uses for materials.
9. Surprising application: closely related to new combinations, a basic item encouraging sensitivity.

2.5.5.4 Product Liability Design Items (Six Items)

1. Elimination of risk.
2. Foolproof design: making the structure safe for the user even if he/she makes an error in operation, e.g., a connector with an asymmetrical structure (top/bottom or right/left) in order to prevent misconnection.

3. Tamperproof design: preventing tampering, such as the removal of a safety device; allowing screws to be turned only with a specific tool.
4. Protective devices: this refers to isolating humans from danger, e.g., a fence for a robot, a guard for a fan.
5. A design with an interlock function: this design allows an operation to be carried out only by following a certain sequence, e.g., when you open the lid of a washing machine during the spinning cycle, the drum stops turning.
6. Warning label: indications for warning users of potential danger in the product.

2.5.5.5 Robust Design Items (Five Items)

1. Stronger materials: the control panel of an elevator (stainless steel panel).
2. Examining shape: avoiding sharp-pointed shapes; smoothed edges recommended.
3. Stronger structure.
4. Designs to reduce or avoid stress: prevent stress from being applied to the entire system.
5. Designs to cope with the user's unconscious behavior: reinforce the design to cope with the user's unconscious behavior.

2.5.5.6 Maintenance Items (Two Items)

1. Securing adjacent space: securing working space and an optimal working posture; optimal working hours; optimal installation layout.
2. Securing restorability: a simplified structure; easy dismantling, easy parts replacement; standardized modular parts; unified plug-in for tools.

2.5.5.7 Ecological Design Items (Five Items)

1. Durability.
2. Enable recycling: easy dismantling; marks on materials; durable materials for long use; simplified parts.
3. Reducing amount of materials.
4. Selecting most suitable materials.
5. Flexible design (e.g., parts replacement).

2.5.5.8 Others (Five Human Machine Interface Aspects) (Five Items)

1. Physical aspect of humans vs. machinery.
2. Information interaction aspect of humans vs. machinery.
3. Temporal aspect of humans vs. machinery.
4. Environmental aspect of humans vs. machinery.
5. Organizational aspect of humans vs. machinery.

Extract the items that constitute design from these five HMI aspects and apply them.

2.6 SYNTHESIZING THE DESIGN

A design proposal can be constructed by creating a visualized idea of the parts that correspond to each of the lower items in the product concept and bringing them together. At such a time, it is also possible for the people involved in developing the product to participate in computer-supported cooperative work (CSCW) by sitting in front of their video display terminals at a specific time, presenting and discussing the visualized idea for each part of a common concept proposal, and constructing a final visualized idea (Figure 2.7).

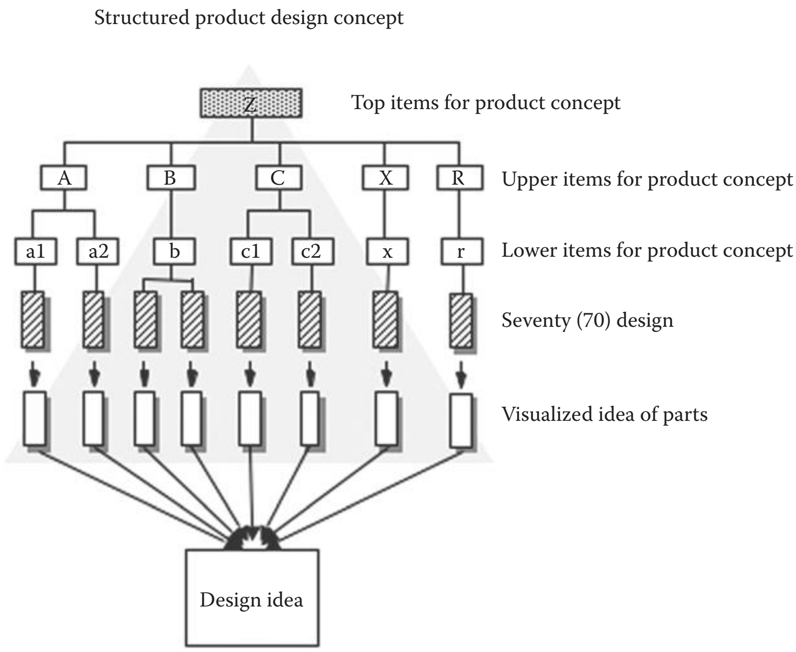


FIGURE 2.7 Visualized design idea based on the structured product design concept.

2.7 EVALUATING THE DESIGN

At this step, the verification of the design idea is to be examined from the viewpoint of confirming the above-mentioned specifications. Furthermore, the effectiveness of convenience and other aspects can be validated with a mock-up and 3P task analysis. (Figure 2.8 illustrates verification and validation.) It is also possible to have monitors compare the result with competitive products in the market by using design rendering and mock-ups and performing the correspondence analysis mentioned above. Again, considering that products are composed of the three attributes of being useful, usable, and desirable (Null and Cherry 1998), the design idea can be evaluated through those attributes. An analytic hierarchy process evaluation is also recommended, examining the lower items of those three items corresponding to the product's features.

2.8 DEVELOPING TUBE FILES: A CASE STUDY (YAMAOKA 2003)

Kokuyo Co. Ltd. tube files, which were developed by using HDT, are summarized below. The 3P task analysis and user interviews were implemented to gather user requirements. A partial outcome of the user interviews is as given here.

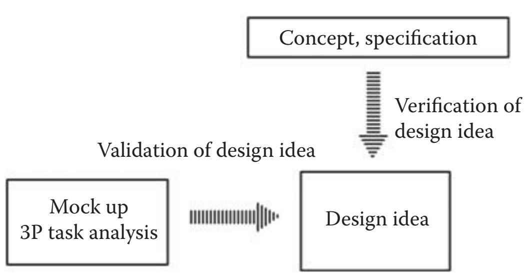


FIGURE 2.8 Verification and validation.

Some of the extracted items are as follows:

1. Needs for large capacity, flexibility (as a good point for collecting many related papers together)
2. Heavy (anxious about carrying it about, working with it, its holding clip)
3. Difficult to see a two-page spread, troublesome in getting pages in and out, easy to see indexes (good appearance), materials that are difficult to handle
4. Impossible to copy while keeping the page in the file
5. Difficulties in the flow of a series of copy tasks (same content as direct observation)

Figure 2.9 shows a part of the 3P task analysis for finding a cabinet.

Next, the product concept was constructed using the requirements acquired by the interview and 3P task analysis. Figure 2.10 illustrates the structured design concept of the tube file. Based on this product concept, the final design was determined (Figure 2.11).

2.9 DISCUSSION

The HDT process and each of its individual steps have been explained. The main features of HDT lie in the use of a structured concept and 70 design items that are prepared in advance in order to visualize a product's image. For a conventional designer, this visualization stage takes place inside the brain. HDT externalizes it and makes it understandable to everyone, thereby facilitating visualization. This eliminates the need for the designer to create a large number of sketches and allows

<table>
<tr><td colspan="6">Scene: Finding out a cabinet</td></tr>
<tr><td rowspan="3">Task
(+subtask)</td><td colspan="3">Pick up problems in "information acquisition → understanding/Judgment → operation" process</td><td colspan="2" rowspan="2">Solution (Requirement)

Seven cues
(1) Examine the product's attribute
(2) Change system
(3) Make proposals for living
(4) Think from the viewpoints of PL and human error
(5) Think from the viewpoints of ergonomics and universal design
(6) Think on the basis of environment</td></tr>
<tr><td>Information acquirement</td><td>Understanding and judgment</td><td>Operation</td></tr>
<tr><td>-Take account of:
(1) The best-suited layout
(2) Easy to see
(3) Emphasis
(4) Clues/necessary information
(5) Mapping.</td><td>-Take account of:
(1) Unclear meaning
(2) Affordance
(3) Vagueness
(4) Feedback
(5) Operational procedures
(6) Consistency</td><td>-Take account of:
(1) Incompatibility with physical characteristics
(2) Trouble</td><td>At the present</td><td>In the near future</td></tr>
<tr><td>Go to the cabinet</td><td colspan="3">(1) No clues to get to the cabinet in which the targeted file is stored.
(2) Guess wrong the cabinet in which the targeted file is stored.
(3) Consequently walk around.</td><td>Clues for the cabinet is needed.</td><td></td></tr>
<tr><td>Search the cabinet</td><td colspan="3">(1) No clues to get to know the content of the cabinet.
(2) The content of the cabinet blacked out by the door
(3) Cabinets with the same shape are lined.
(4) Consequently open the doors many times.</td><td>Window on the door is needed.</td><td></td></tr>
</table>

FIGURE 2.9 Three-Point task analysis for finding a cabinet.

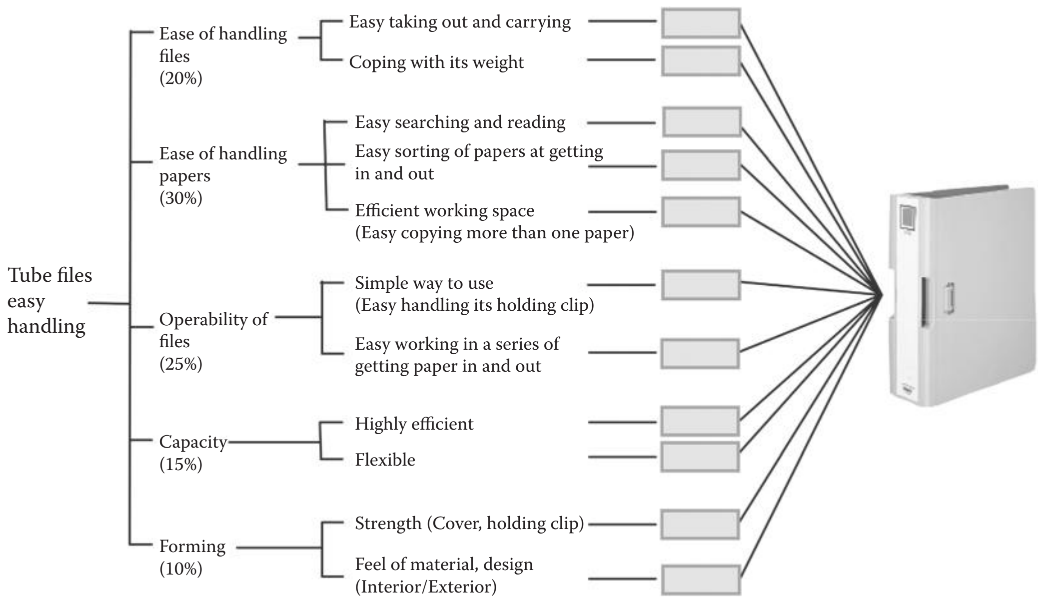


FIGURE 2.10 Structured design concept of the tube file.

a few renderings to suffice. A certain amount of logic is required to create the structured concept, but a concept glossary has been prepared for use by engineers or designers who may feel that the construction task is difficult.

As a case study for the application of HDT, a new Kokuyo Co. Ltd. product, a tube file, was developed in collaboration with a Kokuyo ergonomist. This case study verifies the characteristics of HDT to show that there was no lack of examination, the development lead-time was short, and the use of the structured concept clarified the development guidelines to show exactly what tasks were required.

FIGURE 2.11 The tube file design. (From Yamaoka, T., *Introduction to Human Design Technology* (in Japanese), Morikita, Tokyo, 2003. With permission.)

2.10 CONCLUSION

HDT is a new, logical development method. Its development process begins by gathering user requirements, then constructing a structured concept based on those requirements. Next, the structured concept and 70 design items are used to create a product design proposal. Finally, the design proposal is subjected to verification and validation. As a case study for the application of HDT, a new Kokuyo Co. Ltd. tube file product was developed. The innovative design of this new product verified the effectiveness of HDT.

REFERENCES

Iwamoto, T., and Kawamata, K. 1990. *Single-Case Research Designs*. Tokyo: Keiso Shobo.

Null, R.L., and Cherry, K.F. 1998. *Universal Design: Creative Solutions for ADA Compliance*, 116. Belmont, CA: Professional Publications.

Shinya, A., and Yamaoka, T. 2005. Datamining of Universal Access Log by using In-Situ Ergonomics Method. HCI2005: (CD-ROM) Volume 7 – Universal Access in HCI.

Yamaoka, T. 2001. Human Design Technology as a New Product Design Method. First International Conference on Planning and Design, CD JP003-F 01-10.

———. 2002. A universal design method using 3 point task analysis and 9 universal design items. *Korea Journal of the Science of Emotion & Sensibility* 5 (2): 63–72.

———. 2003. *Introduction to Human Design Technology* (in Japanese), 157–63. Tokyo: Morikita.

3 Persona: A Method to Produce Representations Focused on Consumers' Needs

Eric Brangier and Corinne Bornet

CONTENTS

3.1 INTRODUCTION

At the beginning, ergonomics was aimed at adapting products for professionals working in the fields of safety, industry, aerospace, banks, health, etc. In other words, ergonomics was focused on qualified, skilled, and trained people who would often give us enough time to analyze their tasks, and understand their needs. Methods were employed which produced results that engineers and designers made operational while taking into account technical, time, and budgetary constraints. These methods are well known: task analysis, verbal protocol analysis, job analysis, subjective assessment, knowledge elicitation, accident reporting and analysis, mental workload assessment, etc.

Today, everything has changed: the consumer has become increasingly important. Instead of designing products for a few dozen people working in a company, we are faced with the challenge of designing for millions of consumers. Therefore, ergonomic design has to be completely rethought and our methods have to change accordingly. How can we design products on a worldwide scale? How can we understand the needs of consumers from all over the world, from different cultural backgrounds, with their own personal story, different levels of knowledge, and sometimes with very different perceptive, cognitive, and social characteristics? How can we represent future users since the technology we have in mind hasn't been developed yet? How can we make products that will satisfy a maximum number of users when we can't analyze their work or see how they work? In short, can we use a representation of consumers that is not based on a detailed analysis of their activities and, if so, would it be relevant?

Ergonomics was known for having developed numerous methods to analyze work and workers. Today, however, research is directed toward developing methods that are not only more creative, but also more vague and imprecise. The persona is one of these methods and it stands out as being unusual, innovative, and useful in dealing with future consumers.

The concept of the personas was defined by Cooper (1999), who based his facts on the notion that a user was too confusing to serve as a reference within a product team. The notion of a user was too generic a concept, leading designers to develop products that were designed for everybody but ultimately didn't suit anybody. It was necessary to be able to refer to a specific user, an "almost" real person, a personality type not just a simple user model that was too abstract and superordinate. Cooper pointed out that it is more efficacious to design a product that meets the needs of one specific person than to attempt to satisfy a multitude of potential users. The basic principle of the personas was thus thought out and induced the design of a product adapted to a persona to satisfy all the users it represents (Goodwin 2001). Personas are there to meet the demands of any designer: For his/her product to be desired, used, and appreciated, in one word, the product must delight the consumers. To obtain this, the personas can be used to describe specific consumers, to give them personal characteristics, a face, a name, or even to provide personal details to identify specific expectations.

The aim of this chapter is to present a prospective methodology that enables consumer-focused product design. After defining the persona concept, we will then address the creation and the writing up of the personas. We will present some guidelines to follow the way in which the methodology can be integrated into the design process and the precautions that need to be taken. We will then outline various interpretations concerning the psychological mechanisms behind the use of the personas. The chapter will conclude with the challenges and the limitations of this method.

3.2 DEFINITION: WHAT IS A PERSONA?

How can consumers' needs be met? This is still the key question in ergonomics even if several attempts have been made to answer it. The personas method is complementary to existing methods; it complements approaches focused on user analysis, activity, and the user context. The personas approach proposes focusing on specific or canonical users. The principle is therefore to design a product adapted to different types of people, usually about a few dozen, representing typical consumers. From this viewpoint, the notion of a persona draws on its etymology: The actor's mask, each character playing a particular role during the performance of the play. In order to understand this notion more clearly, we will give a brief history of personas to introduce several definitions (Table 3.1), which will be commented on. We will then illustrate the personas with concrete examples detailing the basic principles of this concept. Finally, we will turn to the paradoxical characteristic of the method.

3.2.1 History and Definitions

The term "persona" comes from the Latin "*personare*," which means "speaks through." In the ancient Greek theater, it represented the actor's mask, which enabled the actors to speak out and adopt the appearance of the character they were playing. Put forward by Jungian psychology, it refers to the "social mask" worn by all humans in order to comply with social standards (Seffah, Kolski, and Idoughi 2009). However, for Jung, the persona is the first archetype that humans encounter when they explore the deepest part of themselves, the deepest part of their unconscious mind. The persona

TABLE 3.1
Personas' Definitions

"Personas are *not real people*, but they represent them throughout the design process. They are *hypothetical archetypes* of actual users. Although they are imaginary, they are defined with significant rigor and precision." (Cooper 1999, 124)

"A persona is an *archetype of a class of users* synthesizing goals and behavior patterns as well as skills, attitudes and environment. The user's characteristics so gathered must be 'ecologically tuned', i.e. they must be effective for the design problem at hand." (De Marsico and Levialdi 2004, 388)

"A persona is an *archetype of a user* that is given a name and a face, and it is carefully described in terms of *needs, goals and tasks*." (Blomquist and Arvola 2002, 197)

"Personas are *fictional user archetypes* based on user research. Through a process of analysis and refinement, the data from user interviews is distilled into *one or multiple fictitious characters*." (Long 2009, 1)

"Personas are *fictitious, specific, concrete representations* of target users. (…) Personas put a *face* on the user – a memorable, engaging, and actionable image that serves as a design target. They convey information about users to your *product team* in ways that other artifacts cannot. Personas will help you, your team, and your organization become more user focused." (Pruit and Adlin 2006, 11)

"Personas utilize our *mind's powerful ability to extrapolate* from partial knowledge of people to create coherent wholes and project them into new settings and situations related to an activity." (Leggett and Bilda 2008, 597)

"Note that *personas include much more information than task or job descriptions*: in the context of a specific design problem, multiple personas could share the same task, or a single persona could represent people dealing with different tasks." (De Marsico and Levialdi 2004, 388) therefore represents our social role mask; the appearance we wish to project to others, the psychological face we are trying to be, and the self that we would like to be. The persona enables social interaction. The persona helps others to recognize and identify us. Nevertheless, Jung reminds us that we are not really consciously aware that we are wearing a mask: The persona doesn't correspond to whom the person is in reality, but to whom others and themselves think they are.

The persona concept has been updated during the last decade and especially taken up by Cooper (1999) in his book, *The Inmates are Running the Asylum: Why High Tech Products Drive Us Crazy and How to Restore the Sanity*. He extended the persona to the domain of software design but without referring explicitly to Jung or the ancient Greek theater. However, in some aspects the persona concept that he developed is based on the traditional usage and etymology of the term (Blomquist 2006). In fact, it was from a criticism of the design processes based on the limitations and constraints linked to the generic user, that Cooper suggested working on identified, distinctive users, having a personal human face. From this basic idea, numerous definitions for persona have emerged (Table 3.1).

Globally, the different quotations, stated in Table 3.1, indicate that a persona is a technique for representing product consumers based on fictional but probable data. The consumer is represented in a simplified archetypal and personalized form: a few words to give him/her an identity, a few sentences to describe him/her, and a photo to give him/her a human appearance. Used to represent the needs and attributes of the different user groups when designing or developing a website, a product, a technical system, or a service, the aim of the personas is to stimulate the designers' ideas by providing them with representations to guide their decisions. A persona is therefore a kind of cognitive instrument to understand the consumers and their goals. Resorting to fictional characters offers several advantages for product development, such as having a simplified view of the consumer or deciding to put the consumers on the same level, thereby affirming the will to satisfy them all in the same way. Personas are usually built from real ethnographical and psychological data, which helps to create a certain number of consumer archetypes.

A persona is therefore a reduction, a simplification, a configuration of distinctive social, affective, and cognitive information; it reproduces primary knowledge governed by assembly, liaison, and transformation rules. The persona is thus an organized whole made up of words and sentences embellished with a personalized photo. These elements are used to describe a series of consumers, supposed to represent customers' values and needs by deduction and all the targeted customers by induction. The persona serves to interact with the designer by creating its own dynamics and a way to enter into contact with reality. In this perspective, the persona is useful when thinking out and guiding decisions on system, product, or service design. Criticisms of personas are based on their prospective aspects. Personas do not describe consumers as they are in the present or the past, but produce tools enabling designers to imagine their consumers in the future. Of course, writing a persona is a complex task, which is difficult to validate. There is no scientific method behind the construction of the personas, as there is not a clear and direct relationship between the real customer data and the personas, which remain fictional and empirical.

It is important to understand that this basic structure (a short text and one photo) is, above all, social, affective, and cognitive:

- It is social because it always puts the consumer in a context that explains the meaning of his/her action, his/her work, or more broadly his/her life.
- It is affective because it humanizes the consumer by giving him/her a face, human values, a name, a personal history.
- It is cognitive because it enables designers to deduce specifications for products, which would be useful for the personas or even better: characteristics for future use.

When it is understood that the persona is the result of a configuration of social, affective, and cognitive information confronting a design environment, it is then easy to see that there is a link, and an exchange between this structure of knowledge and the product designers. This interaction, this relationship, this dynamic enables the designers to draw information for fresh knowledge to be deduced, to design experiences that lead to a better adaptation of the products to the consumers. In addition, an important aspect of the personas is their capacity to synthesize information representing the consumers who accompany the designers during the design process. This unity and continuity generate the idea that the designers are working daily for the same people, people they become familiar with and whom they come to appreciate. During the design process, this unity and continuity will be reinforced by the different experiences undergone by the consumer—personas.

3.2.2 Examples of Personas

For a clearer understanding, some visual aids are needed. The presentation of the personas is always given in two modes.

Firstly, an analytical mode, where each persona is described according to diverse psychological, sociological, and ethnographical data; each persona is described in a few lines, maybe one page. The persona is presented according to three invariants:

- His/her identity or who the persona is: surname, first name, profession, marital status, age, studies, diplomas, etc.
- His/her environment or what he/she is doing in a given context: his/her living conditions, family, special events, and elements of his/her social life.
- His/her preferences or favourite occupation, what he/she wants to be or have: choices, personal opinions, friends, and the scenarios for using the products.

Secondly, the synthetical mode, which assembles all the personas in the same structure (e.g., a website, a table, a chart) in order to emphasize the links between the different personas. This second mode of presentation enables the designer to understand the positioning of the personas relative to each other. The persona aims to provide a global representation covering all the consumers' profiles. With this aim in view, persona comparison tables and/or electronic documents will be used to reproduce the dynamics of the links between the personas' characteristics.

3.2.3 General Properties of Personas

The three examples above (Table 3.2) and a few other research projects (Pruit and Adlin 2006; Rind 2007; Kurosu 2009) highlight the different properties of the personas, which we will now summarize.

3.2.3.1 Persona: To Humanize and Concretize a Generic Abstract Consumer

The persona has a positive and useful aspect. It is sometimes dangerous to expose yourself completely to others. We all need a secret garden to protect us from demands, judgments, and social pressures. The mask helps us preserve the most intimate part of ourselves while interacting with others, enabling us to live in society. In some ways, the persona is an intermediary between the outer world and our most private inner self, a mediator who enables us to enter the network of social interaction and to carry out our role in the human community.

3.2.3.2 Personas: To Go Further than Market Research or Target Marketing

A clear distinction should be made between market research and personas although they are often put into the same category (Head 2003). In fact, personas are fictional, hypothetical, and empirical constructions, whereas target marketing results from market research or sometimes product use surveys. Marketing segmentation consists of classifying consumers according to demographic or geographic data from broad samples (Brechin 2002). These studies aim to highlight the variables

TABLE 3.2
Personas' Examples and Comments

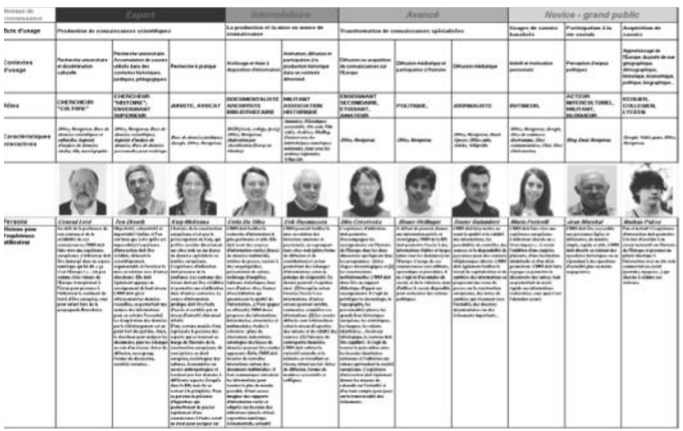
Quickie Persona: *Agatha Zepower*  Agatha works in a fashion company and has amassed a large collection of pictures shot on her mobile phone. These she stores on her home computer and wishes to show her relatives when they visit, as her manner of illustrating what she has been doing, who she has been seeing. How Agatha used "Knowpict": "I like the interface that enables me to create small movies, triggering a search function so that I am able to go faster. Therefore, I often compose new movies. I live a busy life, combining work and socializing with many friends and close relatives. I need a simple system to navigate through pictures and movies. Like many of my contacts, I quickly develop my personal principle of interaction, always using and finding the most direct method for finding what I want."	A persona for exploring design options for an interactive pictures' system. Brief reviews: • Simple and small categorization. • Usable tagline: "Quickie." • Goals are prominent, important use case. • Element of storytelling: succinct narrative story about what's important to Agatha. • Frustrations and needs are presented. • Smiling picture!

Une sorte d'extraversion technologique qui pousse Maria à utiliser la technologie comme médiateur privilégié de ses contacts avec le monde qui l'entoure, et quand cela arrive avec la question européenne c'est qu'un enseignant l'a contrainte à faire un exposé ou à apprendre des leçons...

Nathan Paksa
[jeune homme, lycéen, 16 ans]

Persona « Grand Public - Apprenant »

Profil général du persona	Nathan est lycéen, même si les études la passionnent peu. A cheval sur plusieurs cultures, elle revendique une identité multiple et moderne.
Quel est le rapport du persona aux technologies ?	Nathan est une hyperconnectée. Née avec une souris dans la main, elle a très vite appris à utiliser un ordinateur, un téléphone portable et les jeux vidéo de son grand frère. Son temps libre est une immense zone d'interaction avec des technologies: sms, mms, chat, blog des copines, Wii, Nokia composent son présent et conjuguent son futur.
Quelles idées de l'Europe le persona a-t-il ?	Ce n'est pas son problème, Nathan s'en fiche au quotidien, même si elle sait très bien que l'Europe fixe des directives et autres règles qui l'affecteront tôt ou tard.
Quelles tâches l'amènent à utiliser la connaissance de l'Europe ?	Apprendre ses leçons, faire des exposés, rendre des dossiers aux enseignants.... Pour elle: une série de contraintes !
Qu'est-ce qul l'attire dans la connaissance multimédia de l'Europe ?	Le côté fun, ludique ou explorateur. Nathan tire un véritable plaisir de son interaction avec des technologies nouvelles; mais il faut qu'elles soient attractives, interactives, pleines de surprises et d'émotion.



Series of 11 personas for a digital library (Brangier et al. 2008). Brief reviews:

- Categorization: expertise level of each persona (expert, intermitted, advanced, public).
- Goals are prominent (interesting tying of goals to a story about them).
- Importance of graphic design.
- Tagline for each persona.
- Interesting personal details that give you a sense of each personality and relate very well to his/her work context.
- The text works like an appendix with additional details.
- The table can be an interesting cohort of personas, to help understand their differences. It presents a global view. Table format makes it easy to see how the personas are different. The table helps to easily pick out (the) information that is relevant to each persona. Personal/social life is included in the persona's description, but ignored in the table format. At least, the table includes a personas' scale.

(continued)

TABLE 3.2 (Continued)
Personas' Examples and Comments

A great personas' organization to think and construct the future (Ericsson 2020 project [2009]). Brief reviews:

- Build a shared vision for all designers.
- 450 experts from Ericsson (and elsewhere) have worked on this huge project and built these 18 personas to illustrate how these people will use technology products (76 new applications were imagined) for everyday life.
- Every method goes on: personas, use cases, scenarios, life stories, values analysis, inter-cultural approach, goals analysis, behavior studies, sociological criteria, etc., to distinguish each persona.
- Focuses on the realism of personas, connections between personas are fluent.
- A centric approach that is very useful with a cool interface. A beautiful, rich interface programmed with many hyperlinks leads us from biographies to stories, from scenarios to adventures, from products to trends for the future!
- All imaginable products are represented and linked to personas. That gives explicit ideas for the future, ideas based on representation of possible uses.

Source: From http://www.ericsson.com/campaign/2020_search_application/2020People.html. With permission.

justifying the consumers' buying decision. Although this information can be useful, it is insufficient to determine the functionalities to be included in the product. On the contrary, personas are neither average consumers nor real consumers. As consumer models, they convey behavioral patterns, attitudes, personal motivations, and intentions, which help to define goals concerning the use of a product. In short, marketing segmentation and sociotypes provide quantitative data while personas propose a qualitative description of fictional consumers.

3.2.3.3 Persona: To Design with Personalized Consumers

The persona presents itself as a set of characteristics (tastes, interests, qualities, flaws, etc.), personal traits (including physical features), roles and social values, etc., attributed to fictional consumers. The persona gives flesh and bone to the consumer. These representations made of narratives and photos emphasize the fact that it is more efficacious to design a product that satisfies the needs of one specific person, than to attempt to design a product to satisfy the needs of a multitude of potential consumers. The principle is therefore to design a product adapted to a persona, so as to satisfy all the consumers it represents (Goodwin 2001). Thus, it could be easier to deduce what a consumer wants through a persona than from a qualitative or quantitative product use analysis.

3.2.3.4 Persona: To Design for Future Consumers

In the same way that we are not always our real selves all the time, personas are not real consumers. They are concrete representations of consumers: "hypothetical archetypes of actual users" (Cooper 1999, 124). Thus, the people described are fictional. However, they are based on real data concerning consumers targeted by the product. As such, personas personalize and give credibility to likely consumer types.

3.2.3.5 Personas: To Integrate Consumer Values in Addition to their Needs

Personas are conceived to help design products adapted to customer needs and values. According to Cooper's approach, it means promoting goal-oriented design. A user when interacting with a product is trying, above all, to reach certain goals, which have to be identified in order to be reached.

Personas facilitate the change in mindset. Designers no longer think about their work according to their own priorities, or focus on a single consumer type, but they think from a personas' point of view (Spool 2007). Thus, personas form a design tool. They aid in guiding strategic decisions about which kind of functionalities to implement, or visual aspects to draw up for example. They also facilitate the inevitable arbitration that has to be undergone (Olson 2004).

3.2.3.6 Personas: To Help Designers Enhance their Consumer Representations

Another idea of the personas is that the necessity of adapting the product to each person will provide designers with an essential guide for a product for everybody. The persona can also serve as a communication tool for all the stakeholders involved in the product development process. The idea takes into account "conflicting visions of the product" (Rind 2007, 4), which often co-exist within the same design team. Working together is made easier through being able to refer to common consumer representations, easier to remember than lists of characteristics (Spool 2007). The need to encourage working together is particularly present when working on complex consumer products with the design teams, often made up of a large number of individuals, geographically dispersed and working on different components (Long 2009). Furthermore, this method is part of a participatory design approach, based on mutual learning and cooperation between the consumer and the designer (Blomquist and Arvola 2002).

3.2.3.7 Personas: Firstly for Website Design… then All Types of Products

If at the beginning the method became popular in the field of software design, it is now a tool designed to facilitate the development of consumer, service, and computer hardware products (Pruitt and Adlin 2006) and also websites (Olson 2004): "The model has a specific purpose as a tool for software and product design" (Blomquist 2006, 3). When designing sales products for millions of people, it is a particularly powerful tool for designers determined to use a participative design approach (Grudin and Pruitt 2002).

3.2.4 Paradoxes and Criticisms of Personas

Is it possible to treat a phenomenon as imprecise as future consumer habits of the planet rigorously? Can we really forecast tomorrow's products based on a few lines of description? Personas attempt to give an affirmative answer to these questions by offering a structural solution.

3.2.4.1 Persona: A Structural and Creative Method

The implicit attachment to structuralism means considering that a detailed description of the mind's resources (here our personas) enables us to comprehend the world. The structural hypothesis is based on the fact that it is relevant to consider consumer reality as the combination of recognizable elements belonging to a small number of types, which combined according to the rules, form precisely what we call a structure. The personas resemble a structural method since they enable building associations that link up parts of a discourse. It is the relationship between the elements of the personas (narrative and image) that enables us to discover the significance of the products for the consumers. The persona is a written and visual narrative, which structures the themes of a story about a product or a consumer service. It is based on text-based sequences more or less determined, which provide human-focused arguments for product design. Thus, the persona reveals the structure of the representations of a consumer type.

Far from wanting to be a description of the real, personas present themselves as a structure for creative action. They symbolize a will to act on reality. The persona is thus an exploratory construction of the mind following human-centered principles to which they attribute a predictive value. As they are built in the name of reason (and not of the rational), the persona evokes the evidence through determination. It seeks to determine the general structure of the whole future experience!

To satisfy such a demand, the structural method becomes necessary. It is thoroughly appropriate to describe consumers and future consumers, since it lends itself to a very original renewed analysis of the question of knowledge development. With structuralism, knowledge isn't only the result of demonstrations and experimentations, but it is also useful in creativity, even if it means a risk of reductionism. From this perspective, using the structural method in ergonomics clearly poses the question of the ergonomists' choice and responsibility in his/her struggles, since they themselves become the originators of prescriptions for the future of the products and humans (Robert and Brangier 2009).

3.2.4.2 Persona: An Imprecise Unstable Method

Obviously, the results that emerge from the personas' method lead to results that are not reproducible, but which vary from one writer to another, from one ergonomist to another (Chapman and Milham 2006). The ergonomist working on the personas will examine the capacity of his/her consumer models to fit direct observation. As the project develops, the ergonomist will be led to change the development rules of the personas and will also try to make a minimal number of changes or limit the additional rules he/she should add to his/her index in order to cope with an increasingly complex reality. As a result, the personas are unstable and an ongoing process.

3.2.4.3 Persona: A Reasonable but not Rational Approach

As personas advocate for creativity, they question the rationalism. Developing structures describing identity preferences in context, even if it makes possible the reconstruction of a world through the mind, it doesn't enable its validation. With personas, the proof of the quality of the consumer description is relatively weak, not very reliable, and largely empirical.

3.2.4.4 Persona: The Empirical Construction of an Evident Reality

A personas construction project seeks firstly to tell stories. It focuses particular attention on the effects of life stories as possible sources for ergonomic product design. Empirical data analysis enables the extraction of consumer representation aggregations from sensitive or salient points. These points make up a general framework of details, which enables ergonomists to specify the central values of these configurations, and thus write up the personas.

Writing up personas, as we will see in the following paragraph, should suggest the analogy between what will happen in the future and the description content of the personas. That's why personas are composed of associations that allow us to distinguish between the description and the future effects on the expected causalities. From this point of view, personas should enable development of idea generation circuits (Yu and Lin 2009). The persona thus stimulates the designer's ideation, to the extent that his/her new ideas will seem to be quite obvious to him/her.

The persona is vague, but the product, which will be linked to it, will be well defined. Vague from a factual point of view doesn't necessarily mean vague in the design process. Reading the descriptions of the personas will stimulate the creation of an order in the designers' minds. Consequently, they will seek to adapt their cognition to be directed toward workable goals.

3.2.4.5 Persona: Surpassing Epistemological Tension

The persona suggests an epistemological tension: to the macroscopic irrationality of the future, it proposes microscopic profiling of human beings to come. The nature itself of what is being studied remains vague since the behavior of the human being appears as wavering, vague, ill-determined, not very rigorous, and above all: unstable.

However, in the face of this, personas possess an inner consistency, an identity, values, goals, resource systems, needs, etc.; a whole set of data that are continually optimized by the personas' developer. The nature of the persona itself implies that its inner conceptual relations are not incidental but necessary. The persona enables us to obtain mental operations enabling modification of the reality of the design. The force of the persona lies in its mental consistency, i.e., its capacity to surpass the gigantic uncertainty of the future with statements, which are simple, reasonable, familiar, and above all promote new ideas for innovative products or for services that are better adapted to humans.

The persona is always fuzzy, insufficient, and reductive. However, at the same time, these limitations are also an advantage. Personas offer broad definitions for dealing with consumers and generate useful ideations in product and service design, providing the ergonomists with the necessary knowledge to develop high quality personas.

3.3 HOW ARE PERSONAS CREATED?

Experimentation with personas is difficult. It is impossible to fix the aspects of their content with rigorous demonstration. The development of personas covers a large number of phenomena and facts, which belong neither to illusion nor to pure fantasy, but to the determination of narrative structures, which enable designers to carry out consumer-centered innovations. Yet, very few publications are devoted to a method describing how to create personas (Long 2009). Although no well-defined methodology exists, it is nevertheless possible to identify certain principles likely to serve as a guide. They concern the data sources to be taken into account, the identification of the personas' profiles, the elements to introduce into the descriptions and, finally, conceivable presentation methods.

3.3.1 Data Sources

The creation of the personas should be based on solidly established real data (Goodwin 2002; Pruitt and Grudin 2003; Olsen 2004), which can be collected directly from users, or through more indirect sources.

3.3.1.1 Direct Access Methods

The most highly recommended method is without doubt the direct observation method. It reveals behavior and attitudes that the consumers themselves are often unaware of. The observer will focus his/her attention on “what users do, what frustrates them, and what gives them satisfaction” (Goodwin 2002). However, the consumer’s own point of view is also a rich source of information. That’s why it is valid to interview and organize focus groups, with real or potential consumers. This means that a considerable number of elements can be collected rapidly. However, consumers are not always directly accessible. Furthermore, it is recommended to gather the maximum amount of data, qualitative as well as quantitative (Pruitt and Grudin 2003), which explains the recourse to indirect access methods.

3.3.1.2 Indirect Access Methods

These methods involve contacting professionals who have some knowledge of the consumers. It can be domain experts or heads of marketing, who provide useful alternate sources of information (Olsen 2004). Similarly, data that has been collected to serve other purposes, such as market research surveys, field research, and questionnaires can also be used. Olsen (2004), however, points out that this information should be handled more cautiously than data collected directly from consumers.

Creating personas begins by collecting as much information as possible on the consumer; this data should then be thoroughly checked for its validity: as Goodwin (2002) says: “If every aspect of the description can’t be tied back to real data, it’s not a persona – it’s a creative writing project that should not be used for making critical design and business decisions.” The next stage is to identify the consumer profiles that will be used as a base for the development of personas.

3.3.2 Persona Profiles

Among the publications dealing with persona design, very few mention the transition between the collection of data and the enrichment of the personas. In fact, it is a very tricky operation, which involves identifying all the consumer profiles to serve as a base for the persona. The issue is to include all the behavioral patterns, check for redundancy between the personas in order to limit the number of personas, and provide them with good efficacy, relevance, and inner coherence.

3.3.2.1 Identifying the Personas’ Goals

According to the methodology developed by Cooper (1999), identifying the personas is based entirely on the objectives they are pursuing. After interviews with the consumers, the personas are gradually written up. When several personas share common goals, they are merged into a single persona. This approach, which belongs to directly goal-focused design techniques, is more relevant particularly to software design and from our point of view doesn’t apply to every type of product because when products correspond to small market segments, or when the uses of products overlap or complement each other, it is better to keep the distinctions between the personas.

3.3.2.2 Discovering Relevant Variables

More often, data analysis leads ergonomists and designers to formulate hypotheses about the variables likely to justify the creation of such-and-such a persona. Depending on the cases, the profession practised could be a determining element for the needs to be met using a product; whereas in other situations this element would not play an important role, e.g., family status or level of knowledge. Once these hypotheses are formulated, they can be set against the real data to determine if they make sense (Nielsen 2007). In the affirmative, the consumer profiles can then be built according to the variables identified. If not, it means going back to the data and reworking the analysis.

3.3.2.3 Determining the Behavioral Models Linked to Each Persona

If the choice of personas has been usually selected in an intuitive way, some efforts have been made to try to clarify the approach when possible. According to a method developed by Goodwin (2002), it's a matter of singling out from the data the variables likely to have an influence on consumer behavior. These variables are represented visually on ranges with two ends, which the interviewees were positioned on. Thus, they can be put in an order according to the importance they give to price vs. quality of a product, their level of expertise, or the type of need to be satisfied. This breakdown results in a regrouping of consumers who present common behavioral patterns for the three invariants we have already stated: identity, environment, and preferences. This then enables us to spot particular structures that represent behavioral models. These behavioral models take shape depending on the affective, social, and cognitive criterion, which will enable the basic structure of each persona to be defined. In this way, the personas become distinctive, namely, when considering the specific domain in which these models can be displayed. Finally, the behavior models, which are used to develop the basic structure, will then be enriched by the elements from real or prospective data.

3.3.3 Information to be Integrated into the Personas

"The more specific the persona is, the more effective they are as design tools. With more specific, idiosyncratic details, the persona becomes a 'real' person in the minds of the developers" (Cooper 1999, 128). The aim is to create specific consumers. The level of detail and the nature of the information to be integrated depend on the type of product the personas have been created for. The choices are determined by the product's complexity, how innovative it is, or the variety of consumer profiles. That's why we don't come across consensus among the authors on this subject. Table 3.3 presents an inventory of the main elements, which can be integrated into the persona description. This data is presented in three categories: the persona profile, the aspects related to attitudes and behavior and, lastly, context of use. Note that a full persona description is not necessarily as efficacious as a trait list persona. In fact, Kurosu (2009) compared two methods for writing up personas (full description persona vs. trait list persona), which seemed to produce similar results, although the full description takes much longer to write up.

3.3.3.1 Persona Profiles

As far as personas biographical data are concerned (Table 3.3), the aim is to render the personas credible, easy to remember, and "human." So, there is no need to include too many elements. The risk could be of losing sight of the initial aim of the personas as a design tool and getting lost in superfluous data (Goodwin 2002). Personas, just as fictional characters, have to be able to attract attention. Their description should not only enable us to understand the underlying motivations that bring them to life, but also to foresee their behavior, which means creating "rounded users" (Nielsen 2002, 103). Consequently, predictions relative to the behavior of personas in the scenarios will be based on elements linked to the following aspects:

- Biological: they concern varied data such as gender, age, and condition of health or physical appearance.
- Sociological: social class, level of studies, religion, which can also have an influence on the type of products looked for.
- Psychological: personality traits, the way in which a person wishes to realize his/her life, and even his/her sex life can further our understanding for the development of some of his/her needs and behavior, as well as the emergence of behavioral patterns.

The elements that will give the personas their definite personalities will also be added to this profile. Then, they will be given a name and a photograph. As far as the photograph is concerned, the question is whether it is the most well-adapted support to give a visual representation of the persona. Studies confirm that it makes personas seem more credible in contrast to a simple illustration (Long 2009). On the other hand, it appears that photographs of realistic puppets attract the attention more than photographs of real people (Nieters, Ivaturi, and Ahmed 2007); but these results have yet to be confirmed.

TABLE 3.3
Characteristics of Persona-Building Information

Components	Examples	Authors
Synopsis of the persona identity: brief background of the persona	Name, photo, picture.	Cooper (1999)
	Email address. Current address.	Pruitt and Grudin (2003), Kurosu (2009)
	Quotes. Tagline.	Pruitt and Grudin (2003)
	Birth place. Typical day.	Pruitt and Grudin (2003)
	Physiological aspects: sex, age, height, and weight. Physical abilities/disabilities.	Nielsen (2002), Olson (2004), Rind (2007)
	Sociological aspects. Social network. Social role. Social class. Occupation. Education. Academic background. Leisure activities. Hobbies. International considerations. Religion and nationality.	Nielsen (2002), Goodwin (2001), Pruitt and Grudin (2003), Olson (2004)
	Psychological aspects. Sex life. Character and personality. Intelligence. Specific knowledge, skills, abilities. Learning style. Mental disabilities.	Nielsen (2002), Goodwin (2001), Olson (2004), Rind (2007)
	Language and ethnicity.	Olson (2004)
	Income. Housing type.	
	Geographic aspects. World region. City. Urban or rural. Climate.	Olson (2004)
	Status: primary, secondary.	Head (2003)
Attitudes and behaviors refer to the actions or reactions of the persona, usually in relation to a use	Percentage of overall users. Social influences.	Olson (2004), Pruitt and Grudin (2003)
	Fears (about life, career, and business). Frustration. Beliefs, attitudes, and motivations. Needs. Attitude to the job or the task.	Pruitt and Grudin (2003)
	Life goals (interpersonal desires, professional ambitions, etc.). Emotional goal. Use goal.	Goodwin (2001), Nielsen (2002)
	Succinct narrative story.	Cooper (1999)
	Use boxes highlighted.	
	Experience goals.	Goodwin (2001)
	Attitude toward product/brand. Emotional characteristics of the user.	Olson (2004), Rind (2007)
Context of use should be considered from the very early stages of persona specification	Surrounding environment. Description of the spaces.	Olson (2004), Goodwin (2001)
	Task context. Interaction with the product: frequency, regularity, predictability.	Olson (2004)
	Brand relationship.	Olson (2004)
	Context of actions: home, office.	Marcengo, Guercio, and Rapp (2009)
	Characteristics of use. Specific difficulties. Security, legal restrictions, robustness, maintenance, documentation, learnability. Persona scale.	Olson (2004)
References	Source materials.	Pruitt and Grudin (2003)

3.3.3.2 Behavior and Attitudes of Personas

Behavioral aspects enable the product to be situated in a global perspective, in relation to people's values and beliefs (Table 3.3). They concern, for example, the goals pursued in life, the type of needs at an interpersonal level, and professional ambitions (Nielsen 2002). It is also interesting to know the market share each persona represents, even if that doesn't mean that attention should be focused on personas representing the largest market (Goodwin 2001). For instance, designing a product for a person with a disability could also help to satisfy a large number of consumers.

The description of the goals sought by the users, when interacting with the product, is a key element provided by the personas description (Olson 2004; Goodwin 2001). It goes beyond a simple description of tasks and enables an identification of the motives behind the behavioral patterns. It is also useful to know the goals linked to the experience with the product. They represent the type of sensations that the consumer wishes to experience through the product, such as pleasure and emotion, but also fear or surprise. Whatever the case, the goals sought, and the final objectives, which should be reached through using the product, are key elements to be detailed in the description (Goodwin 2001). Nevertheless, this goal-focused approach should be adopted with some reservation. Depending on the type of product or customer profile, it could turn out to be unsuitable. When designing products for children, it is in fact more useful to consider the needs to be satisfied according to the child's age rather than the goals sought (Antle 2006). Children are not focused on reaching precise goals, but more on the possibility of experiencing rich and intense interaction.

3.3.3.3 Context of Use

The description of context of use gives information about the environment in which the product will be used (Table 3.3). The global consumer environment should be presented according to the goals pursued. The task context is also addressed with elements on the nature and frequency of the interactions, or the information used when using the product. This information allows for justification of the constraints to adhere to concerning functionality, accessibility, security, regulations, as well as flexibility and product robustness.

3.3.4 Writing up the Personas

Once the elements in Table 3.3 are identified, they can be regrouped in a narrative form of one or two pages (Goodwin 2001) using a paper or electronic medium.

3.3.4.1 Recommendations for Personas Writing

Several presentations are possible and the ergonomist is quite free to choose his/her writing style (Table 3.2 shows several examples). The literary presentation rather than a list of items will contribute to personalizing the consumer profile.

Globally, the elements integrated in the personas description should not only be based on solidly established real data, but creativity counts a lot too! It is recommended to regroup the elements on a single document, paper, or electronic medium (Pruitt and Grudin 2003); hence justifying the scenarios that are subsequently developed. Accessible to the designers, this representation of likely future consumers also enables the link between the real data with the products and the lifestyles for each element to be highlighted, there by contributing to bringing the personas to "life" for the design team.

Finally, writing up personas is in some ways similar to writing a literary work. It depends on the author's skills in analysis and summarization, his/her understanding of the project and, of course, his/her writing skills. Too often ignored, writing up is, however, a determining factor of the quality of reading and understanding of the personas. Writing up the personas should adhere to a writing policy based on following a few steps (Barcenilla and Brangier 2000) resulting in an ergonomic document:

- Have a textual (words, headings, sentences) and visual (photographs, images, graphics) architecture that give a sense to the information about the persona.

- Be careful about readability: i.e., presentation and organization of the information in the text but also the choice of medium (graphical presentation or textual, tables, etc.).
- Structure the reading indices (presence of headings, paragraph settings, columns, new lines, indented lines, line spacing, titles, numbering of paragraphs) and also use typographical processes, such as typeface, bold type, etc.
- Pay attention to the general aspects of the layout and have a homogenous coding of the text (space the writing out, leave spaces between paragraphs to allow for easier visual scanning of text, spacing should be even between words, lines, paragraphs, sections, etc.).
- Verify the choice of photographs and graphic design, showing that they really correspond to the connotative aspects, which reinforce the descriptive aspects of the personas.
- Facilitate access to relevant information. The personas readers can have different aims: scanning, looking up, reviewing, reading in detail, etc. To do this, they have to be able to browse easily through the text. Textual browsing can be made easier with good typographical processes and a relevant use of what we could call "access structures" to information. These structures are generally presented in the form of plans, table of contents, indexes, hyperlinks, navigation tabs, etc., which should comply with ergonomic recommendations.
- Reinforce graphic readability by increasing the use of illustrations (tables, diagrams, photographs, etc.).
- Write simply! Think about simplifying the semantic and syntactic structures: use short and simple sentences (maximum 20 words); make comprehension easier by placing the main proposition at the beginning of the sentence. Use the active form where possible because passive form statements are more difficult to understand; avoid negative phrases and double negatives.
- Try to develop cooperation with the designers: take into account the characteristics of the people who are going to read the personas. The personas are also to be set out in a way that is compatible with the mental organization of the designers' task: the aim is for the designer to have a clear perception of the personas to fulfill the task involved in design. The mediums used to present the personas (paper or electronic) should be adapted to the conditions of use at the design stage. In summary: the idea is to stimulate designers' creativity.

3.3.4.2 Number of Personas

To obtain distinctive, easy to remember personas, the number of personas should be limited to three to seven (Blomquist and Arvola 2002; Head 2003). However, there can be as many as 12 when working on large-scale projects (even 15, e.g., for the "Ericsson project 2020"). The aim is not to design a product for all the personas, but to have a global view of all the consumers to know whom the product is not intended for (Cooper 1999).

3.3.4.3 Types of Personas

There is often a distinction made between primary personas and secondary personas.

- The primary persona is one of the main consumers (or users) of the product or service. He/she uses the whole product or a large part of its functionalities.
- The secondary persona is one of the other consumers (or users) for whom adaptations of the product would be interesting. He/she corresponds sometimes to a variant of the primary persona or sometimes with more specific additional needs not covered by the main persona. The assignment of the secondary persona is, therefore, to complete consumer representation by being a more exhaustive model.

In addition to these two personas, Head (2003) has introduced the notion of a negative persona. It represents the user for whom the product isn't designed. It represents the direction that shouldn't be taken, the functions that are not interesting to develop, and usages without interest.

Generally, the design is centered on the primary personas, who guide the decision-making process (Head 2003). If there are more than three, it usually means that the design problem is a large-scale one. In this case, it probably won't be possible to satisfy three different profiles with the same product (Cooper 1999). As for the needs of the secondary personas, they will be taken into account as long as they don't counter the satisfaction of the primary personas.

In certain projects, other types of personas corresponding to a lower priority order can be created. Olson (2004) proposes three other types:

- The "unimportant personas" represent very low priority consumers who will hardly use the product.
- "Affected personas" represent people who don't use the product themselves but who are still affected by its use.
- "Exclusionary personas" (or "negative personas" according to Head [2003]), represent consumers for whom the product is not directed toward, thus limiting the number of discussions and pitfalls for the production team.

To sum up, these broad guidelines aim to enlighten ergonomists who wish to embark on the adventure of personas writing. In no way does it impose a recognized methodology, given that in practice, designers "adapt and make design tools their own" (Chang, Lim, and Stolterman 2008, 439).

3.3.5 Implementing the Personas in a Project Team

Once the personas have been created, the challenges are

- To gain the support of the team in order to center attention on personas throughout the design process
- To validate the personas
- To associate the personas method with other pre-existing methods to enrich knowledge of customers
- To integrate the personas into a global approach managing consumer information

3.3.5.1 Introducing the Personas

There are several ways of including the personas in a design process; however, there are some principles to be taken into account. The personas are usually introduced to the entire design team at a meeting. A written description is given to each participant, including for example a page on each persona, a diagram representing the type of interaction they have with the product, and a summary table enabling the comparison of the goals and the main characteristics of the personas (Freydenson 2002). Throughout the oral presentation, the designers of the personas should speak about them as if they are real and as if they know them. The aim is to try and get the designers to feel close enough to the personas to like them. "Remember, you want your audience to like (though not necessarily agree with) the personas. There is little motivation to try to understand or design for people you hate" (Freydenson 2002).

After the first meeting, efforts must be made to ensure that the personas are kept in the designers' minds. Posters can be put up in the offices; cups with personas on them can be distributed; keeping in mind that it's the primary personas who are at the heart of the communication process.

The personas will then be used to think about original and innovative products at two points in the design process. Firstly for Goodwin (2002), implementing the personas is carried out during the pre-design stage. In this way, they form a framework to guide the designers' decisions. But secondly, Pruitt and Grudin (2003) consider that developing the persona is an integral part of the life cycle of the design process. They are enriched and modified continuously as new additional consumer information appears.

Note that too many personas are still based on criteria of plausibility or feasibility and not of validity. However, one of the conditions for successful personas is, on the one hand, that the designers find a relatively reliable image of how the consumer lives and, on the other hand, that the consumers are able to benefit from ergonomic products.

3.3.5.2 Personas Validation Problems

Validating the personas is an extremely complex problem, notably because they are mainly prospective and speculative. There has been too little research carried out to be able to quantify the advantages of using this technique (Brangier et al. 2010).

Validating personas is in opposition to developing personas. Whereas the purpose of development is to determine the facts that validate the model, validation should define the facts that invalidate it. This validation viewpoint is very much present in the domain of safety and security; where engineers aren't seeking to show that their application functions well. On the contrary, they are seeking to identify all possible sources of malfunctioning, which will then enable them to guarantee a high level of quality and performance. With this same idea, validation is envisaged in two complementary ways: extrinsic and intrinsic.

- Extrinsic validation of the personas proposes evaluation criteria focused on the use of the personas by the designers: The designers' satisfaction level, acceptation of the personas by the partners, ease of use of the personas for marketing managers, interest for the progression of ideas in the company, technical and practical integration of personas into the design process, measure of the development of cooperation between stakeholders, and the impact of the personas on the management of the design teams.
- Intrinsic validation is linked to evaluating the scientific quality of the personas and their capacity to improve product and services design. Intrinsic validation is also based on the model's confrontation with empirical data and the reactions of experts. Long (2009) considers that validating the personas means validating the tools that guide the decision-making process. In a five-week experiment, this author compared the designs of students with and without personas to produce a computer application. The results were a form of validation and showed that personas helped in producing a more convivial product, and were a significant advantage during the research and design stages.

In short, using personas as a method for communicating consumer requirements in a collaborative design environment has become well established. However, as they have consumer representation and creativity goals, the personas cannot be judged solely according to valid or invalid criterion. All said and done, the validation procedure cannot limit itself to classifying personas as being valid or not valid models. The validity of a representation and an idea stimulation model is both a judgment of its acceptability by designers and stakeholders and a measure of its efficacy to generate a design that is more adapted to the consumer. As a result, validation is not only a process for judging the acceptability of the personas in a real situation, but also a way of correcting the elements of their content. Validating the personas means listening to designers' reactions, improving the methodology, and finally, passing judgment on their social utility both for the designers and the consumers.

3.3.5.3 Combining Personas with Other Methods

At first, personas were more or less envisaged as a tool for discussion (Cooper 1999), then they tended to become the elements of "alter ego design" (Triantafyllakos, Palaigeorgio, and Tsoukalas 2010) to fit into creative and participative approaches. These authors, while retaining their initial personas philosophy, have gradually developed their tools for optimal use.

Very often the tools are presented in a matrix form enabling a visual representation of cross-referenced results (Tables 3.4 and 3.5). The "feature-persona weighted priority matrix" developed by Pruitt and Grudin (2002) indicates for each persona, the value he/she gives to a particular

TABLE 3.4
Example of Matrix to Help Persona Utilization: Significance of the Functionality and Use Frequency

		Significance of the Functionality	
		Low Significance	**High Significance**
Use frequency	**High intensive use of the product**	PERSONA (low/high) Low significance/high use frequency *Functionality to make easily accessible*	PERSONA (high/high) High significance/intensive use frequency *High-priority functionality*
	Non-intensive use of the product	PERSONA (low/low) Low significance/low use frequency *Low-priority functionality*	PERSONA (high/low) High significance/non-intensive use frequency *Second kind of functionalities, to make easily accessible*

characteristic and the market share he/she represents. The characteristics to be considered as having priority can be identified by calculation: those considered as being important for a large share of the market. Orders of priority can be attributed to envisaged characteristics.

Following the same principle, we suggest using matrixes to guide decision making on contents and functionalities:

- The first is based on frequency of use and the importance of a particular functionality or particular content to reach the personas' goals (Table 3.4).
- The second is based on a matrix crossing relevant market characteristics with personas (Table 3.5).

These matrixes allow the designers to focus on the elements frequently used by many users and considered as being important. To validate the final decision, Olson (2004, 16) suggests asking two "fit criteria" questions: "If the product presents this or that characteristic, what is the personas

TABLE 3.5
Example of Graphic Representation to Help Persona Utilization: Use of Relevant Criteria for the Positioning of Each Persona

	Examples of Personas		
			
Examples of Criteria to Define the Importance of Each Persona for a Project	**Peter Perret**	**Lucy Heitz**	**Elisa Woo**
Marketing target	++	++	+
Credibility	+	−	+
Profitability perspective	+	−	+
Growth perspective	+	++	−
Enthusiasm for innovative products	+	−	++
Importance for the brand	+	++	+

degree of satisfaction?" Equally, "If this characteristic is absent, what is his/her degree of dissatisfaction?" Both questions have to be asked because the answers won't necessarily be the same. A consumer might actually express average satisfaction concerning one particular characteristic, which could in fact cause greater dissatisfaction if it was absent. Thus, in addition to the personas, methods for visualizing consumer data have been developed to favor optimized decision making.

3.3.5.4 Enhancing Consumer Knowledge through the Personas

Once they have been introduced into the company, the personas have to pursue their own lives. If they are neither read nor used, the ergonomist may have the feeling of having written up documents that are pointless.

Is the persona a simple narrative or a tool to help design and decision making? To acquire the status of an instrument for future design, the personas must be handled like any other type of document useful for production purposes in a company. Consequently, depending on the size and aims of the company, various tasks should be carried out, including:

- Designating skilled team leaders to improve and handle documents related to personas.
- Integrate the personas into in-house communication systems: familiarize the employees with the personas so that they get to know their future customers better.
- Develop participation and working with the ergonomist: the designers will be involved in the development, writing up, validation, and progression of the personas.
- Analyze products and services generated with the personas and have a critical review follow up of what is designed.
- Test the progression of the personas, and have discussions with the people concerned, come to agreement on the new personas.
- Set up a filing and management system of all the documents related to consumer information.

The personas are part of an organizational framework that gives great importance to knowledge management. Continual technological evolution implies, and will increasingly imply, a continual acquisition of fresh knowledge that will be facilitated by an adapted in-house organization. However, before developing the personas, it is necessary to understand why the personas work. Let's briefly look into the theory to understand the psychological foundations of this technique.

3.4 THEORETICAL BACKGROUND: WHICH THEORIES CAN EXPLAIN THE IMPACTS OF PERSONAS?

If a large number of researchers and designers highlight the personas as being a powerful design tool, very few of them wonder about the reasons why this method works. Why do personas enable designing products adapted to consumers' needs? What are the psychological mechanisms that preside over the use of this tool?

Firstly, it is the persona's role as an actor, which comes into play both at the creation stage and at the final use stage, that bridges the gap between the designers and the end consumers. This "acting" is itself drawn from purely human abilities: empathy and theory of mind. Lastly, the design can be viewed as a creative process; as such, the personas would act as constraints capable of facilitating the generation of ideas.

3.4.1 Acting Theory

3.4.1.1 Personas as Character Actors

Theater actors initially draw their inspiration from real information to be able to work on their roles. They observe people who share common points with the characters, familiarize themselves with the environment, context, and objects. In the same way, personas' creators start by using real consumers' data. They then breathe life into their persona, attributing them coherent characteristics and behavioral patterns. Like actors, they work on building rich, likeable, and credible personas. From a metaphorical point of view, personas' writers are seen as writers giving life to fictitious characters. Dramatization, defining the characters, developing the script, staging the scenarios, as well as creating imaginary settings bring the personas method closer to an actor's work.

From the methodological point of view, the principle is relatively simple. After a brief applied drama course, the designers draw from their ability to improvise and act out what we all possess, to bring the personas into being (Kantola et al. 2007). Firstly, this requires familiarization with the ethnographical data and research gathered. This is followed by different exercises, such as theater workshops, focusing on improvisation exercises. Gradually, the personas will come to life inside the designers' minds, thereby enhancing the design process. From simple consumer profiles written on paper, they are transformed into real characters. Compared with the personas developed by more standard methods, they are more credible. Placed into a socio-cultural environment, they interact with the other personas and are rich enough to adapt to new situations. To sum up, the resulting characters are the fruits of the painstaking and implacable task of data gathering and acting. The personas can be presented in a dynamic form by the actor or in a graphic and textual form. The aim sought after is to show the designers the process of how the actors develop their characters from real data and succeed in revealing the deeper motivations that were unknown at the beginning.

3.4.1.2 Roles Played by the Characters

The reference to the theater is not limited to the creation of the persona. It takes full meaning when design choices using the personas have to be taken. As Cooper (1999, 134) states: "We become character actors, inhabiting the minds of our personas." Using scenarios as a base, the designers are always the actors who bring the personas they have created to life: "We play our personas through these scenarios, like actors reading a script, to test the validity of our design and our assumptions" (Cooper 1999, 179). The designers put their own point of view aside and adopt the knowledge and feelings of the consumers. This idea is based on applying a simple principle: if the persona is satisfied, the product will be suitable. During the scenario, the designers become identified with the personas and adopt their preferences, needs, and goals. Projection and identification serve to deduce the reactions of the persona, just like an actor deduces the behavior of his/her character in a new situation. Given that this persona represents the consumers, it is the behavioral patterns of the consumers that are deduced (Grudin and Pruitt 2002).

3.4.2 Empathy and Theory of Mind

Which psychological mechanism do designers follow to succeed in making assumptions on personas' behavioral patterns? To answer this question, some authors mention empathy, which can be defined as "this natural ability to understand the emotions and feelings of others, whether one actually witnessed his or her situation, perceived it from a photograph, read about it in fiction book, or merely imagined it" (Decety and Jackson 2004, 71). Empathy is therefore the general mechanism according to which a person can understand the attitudes, emotions, feelings, beliefs, or mental states of others.

As far as the personas are concerned, bringing out empathy will serve to think of the personas as specific and real people and allow the designers to feel empathy toward the consumers. It is the same mechanism as the one that occurs between the audience and the characters of a film, the difference being that the personas are not derived from fiction, but are the result of data collected from real consumers. Consequently, the designers and the consumers will become closer. This explains why, thanks to personas, designers no longer need to use excessive documentation: they "put themselves in the persona's shoes" (Rind 2007). Because of the increase in empathy, designers will design products for users (Nielsen 2007) and will deal with design problems linked to the users and no longer to themselves (Kantola et al. 2007). Through empathy, the designers may come out of their reference context to adopt the context of the consumers.

Theory of mind, or “mentalizing,” can also be called on to explain the effects of the personas. It refers to the ability of each one of us to explain and predict the behavior of others, and to understand that they have different mental states to our own, pertaining not only to emotions, but also desires and intents (Gallagher and Frith 2003). Knowing whether theory of mind and empathy overlap is still the subject of numerous debates. But this concept, in our case, enables going beyond the notion that is often attached to empathy: the desire to respond with compassion to others in distress (Decety and Jackson 2004). Hence, personas make good use of the fact that based on partial information we are able to make inferences and predictions about people we don’t know (Pruitt and Adlin 2006). However, the adults’ ability to distinguish their own beliefs from those of others doesn’t occur routinely (Keysar, Lin, and Barr 2003). Personas could thus be considered as a support that favors brief identification with others to implement the ability to adopt different points of view, making it possible to keep in mind different types of consumers.

3.4.3 Constraints Management Theory

It is also possible to interpret the efficacy of the personas from another angle: the creativity angle. Designing can actually be considered as a creative activity (Bonnardel 2009). Using personas would therefore be a creative support, as a “process through which a person becomes aware of a problem, difficulty, lack of knowledge which he/she has no known or perceived solution; he/she seeks a possible solution by forming hypotheses; he/she evaluates, tests, or modifies his/her hypotheses; and communicates the results” (Torrance 2004, 57). More precisely, personas are a set of constraints, or frameworks, which organize the imagination and simplify specifications and structures to optimize the consumers’ future. From this point of view, it becomes evident that personas represent constraints that are propitious to the development of creativity. As such, they can facilitate designers’ idea generation. This hypothesis is based on the “constraints management theory” (Bonnardel 2006, 68), according to which seeking creative solutions or idea generation is facilitated by two major processes:

- Creativity based on analogies with a model (analogy-based design)
- Creativity based on constraint management (constraint-based design)

The constraints, whether formally prescribed, added by the designer, or implicit, help to define the scope of research. The act of creation is not characterized by the absence of all types of constraints; on the contrary, constraints are part of the creative process as they help in the production and selection of ideas. From this perspective, personas make the designers think “according to,” leading to cognitive design efforts that reduce reasoning according to their own knowledge and priorities. Furthermore, we observe that the designers’ abilities to innovate are strengthened when using personas (Kantola et al. 2007). Personas may be understood as a technique promoting idea generation, as they form constraints that favor the production of creative solutions.

To summarize, three theories can be invoked that are complementary enough to explain the personas ability to develop new ideas for designing products and services. However, it should be reminded that the psychological and cognitive mechanisms involved in the personas technique remain at a hypothetical stage. New, in-depth research should be carried out to thoroughly test these theories.

3.5 CONCLUSION

The persona-based method thus proposes considering that one fictitious character can individually represent a whole category of likely future consumers. During the writing of the personas, a set of attributes (textual, contextual, and meta-textual) will be assigned to this archetypal consumer, enriching his/her profile in order to efficiently illustrate the traits that are prominent and determinative for product design. In a few lines, the persona’s traits enable designers to create scenarios for product or service use on the one hand and, on the other, they enable distributors to develop a marketing strategy for the same product or service.

As we have seen previously, creating personas is fastidious work that implies observing some recommendations in order to produce relevant categorizations that are able to prove their effectiveness in product design and marketing. In such a way, the personas tool can enable:

- Guiding design and marketing decisions
- Giving shared representations within a collaborative project
- Keeping designers focused on key elements
- Determining the priority of certain functions, needs, desires, and goals
- Taking useful action following up certain projects
- Organizing consumers in a hierarchy according to an explicit logic
- Prioritizing goals
- Reassuring designers on which path to keep to and the aims that are to be achieved
- Providing simplified but effective and useful representations to help in understanding complex situations
- Apprehending through scaled-down representations, complex occupations or emerging consumption patterns
- Highlighting specific characteristics of certain consumers
- Facilitating building consensus with the marketing department

Briefly, personas promote consumer-centered design, providing the means to overcome the difficulties encountered with real people-related information.

The controversial aspects of the personas method are that scientific studies are rare, experimentation is often impossible, and there has not been a monograph on this topic for several years. Unstable, artificial, irrational, speculative, arbitrary, etc., the words used to criticize the personas are sometimes harsh. There's no way to explicitly define a relative perfection principle for the personas. However, it's still possible to assess their qualities of being able to reflect the consumer's experience. If it's impossible, without a prior methodological choice, to organize the personas' qualities in a sequential order, it is nevertheless possible to agree on the fact that the personas method has some qualities: to propose prospective elements on future experience (Robert and Brangier 2009). As there's no a priori access to the whole future experience, personas are founded on this approximate understanding of the future by way of structural categorizations of consumers.

The persona simultaneously leaves us to assume our responsibilities as ergonomists and decision makers, but gives clarification to the choice we make from other eventual choices. The personas provide the elements to enable choice. Hence, the personas' challenge is to supply the evidence for thinking the future!

REFERENCES

Antle, A.N. 2006. Child-personas: Fact or fiction? In *Proceedings of the 6th Conference on Designing Interactive Systems*, 22–30. ACM (ISBN: 1-59593-367-0).

Barcenilla, J., and Brangier, E. 2000. Propositions pour une intervention en ergonomie des aides textuelles au travail. In *Illettrisme et milieu de travail*, ed. Ch. El Hayek, 357–68. Paris: La documentation française.

Blomquist, A., and Arvola, M. 2002. Personas in action: Ethnography in an interaction design team. In *Proceedings of the Second Nordic Conference on Human-Computer Interaction*, 197–200. New York: ACM (ISBN: 1-58113-616-1).

Blomquist, S. 2006. The user as a personality: A reflection on the theoretical and practical use of personas in HCI design. 1–13. http://www.it.uu.se/research/publications/reports/2006-049/2006-049-nc.pdf (accessed January 15, 2010).

Bonnardel, N. 2006. *Créativité et conception – Approches cognitives et ergonomiques*. Marseille: Solal Editeurs.

———. 2009. Activités de conception et créativité: De l'analyse des facteurs cognitifs à l'assistance aux activités de conception créative. *Le Travail Humain* 72 (1): 5–22.

Brangier, E., Barcenilla, J., Bastien, J.-M.-C., Dinet, J., Michel, G., and Vivian, R. 2008. *Analyses diagnostiques et prospectives pour la bibliothèque numérique www.ena.lu.* Rapport de recherche, document interne. CVCE & Université Paul Verlaine Metz.

Brangier, E., Bornet, C., Bastien, J.-M.-C., Vivian, R., and Michel, G. (revision). Mesure de la capacité des personas à générer des idées dans la conception de projets informatiques. *Le Travail Humain.*

Brechin, E. 2002. Reconciling market segments and personas. http://www.cooper.com/journal/2002/03/reconciling_market_segments_an.html (accessed January 15, 2010).

Chang, Y., Lim, Y., and Stolterman, E. 2008. Personas: From theory to practices. In *Proceedings of the 5th Nordic Conference on Human-Computer Interaction*, 439–42. ACM (ISBN: 978-1-59593-704-9).

Chapman, C.N., and Milham, R.P. 2006. The persona's new clothes: Methodological and practical arguments against a popular method. In *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting*, 634–36. http://cnchapman.files.wordpress.com/2007/03/chapman-milham-personashfes2006-0139-0330.pdf (accessed January 15, 2010).

Cooper, A. 1999. *The Inmates are Running the Asylum – Why High-Tech Products Drive Us Crazy and How to Restore the Sanity*. Indianapolis, IN: Sams.

De Marsico, M., and Levialdi, S. 2004. Evaluating web sites: Exploiting user's expectations. *International Journal of Human-Computer Studies* 60 (3): 381–416.

Decety, J., and Jackson, P.L. 2004. The functional architecture of human empathy. *Behavioral and Cognitive Neuroscience Reviews* 3 (2): 71–100.

Ericsson 2020 project. 2009. www.ericsson.com/ericsson/2020-081217/ (accessed July, 2009).

Freydenson, E. 2002. Bringing your persona to life in real life. http://www.boxesandarrows.com/view/bringing_your_personas_to_life_in_real_life (accessed January 25, 2010).

Gallagher, H.L., and Frith, C.D. 2003. Functional imaging of theory of mind. *Trends in Cognitive Sciences* 7:77–83.

Goodwin, K. 2001. Perfecting your personas. *Cooper Newsletter*, July/August. http://www.cooper.com/journal/2001/08/perfecting_your_personas.html (accessed January 15, 2010).

———. 2002. Getting from research to personas: Harnessing the power of data. http://www.cooper.com/journal/2002/11/getting_from_research_to_perso.html (accessed January 15, 2010).

Grudin, J., and Pruitt, J. 2002. Personas, participatory design and product development: An infrastructure for engagement. In *Proceedings of Participatory Design Conference*, Palo Alto, 144–61. http://research.microsoft.com/en-us/um/redmond/groups/coet/grudin/personas/old%20versions/personasold.pdf (accessed December 15, 2010).

Head, J. 2003. Personas: Setting the stage for building usable information sites. *Information Today/Online* 27, 4.

Kantola, V., Tiitta, S., Mehto, K., and Kankainen, T. 2007. Using dramaturgical methods to gain more dynamic user understanding in user-centered design. In *Proceedings of the 6th Conference on Creativity and Cognition*, 173–81. ACM (ISBN: 978-1-59593-712-4).

Keysar, B., Lin, S., and Barr, D.J. 2003. Limits on theory of mind use in adults. *Cognition* 89, 25–41.

Kurosu, M. 2009. Full description persona vs. trait list persona in the persona-based sHEM approach. In *Human Centered Design*, ed. M. Kurosu, 230–38. Lecture Notes in Computer Science no. 5619. San Diego: Springer Verlag.

Leggett, M., and Bilda, Z. 2008. Exploring design options for interactive video with the Mnemovie hypervideo system. *Design Studies* 29 (6): 587–602.

Long, F. 2009. Real or imaginary: The effectiveness of using personas in product design. In *Proceedings of the Irish Ergonomics Society Annual Conference*, 1–10. http://www.frontend.com/products-digital-devices/real-or-imaginary-the-effectiveness-of-using-personas-in-product-design.html (accessed December 15, 2010).

Marcengo, A., Guercio, E., and Rapp, A. 2009. Personas layering: A cost effective model for service design in medium-long term Telco research projects. In *Human Centered Design*, ed. M. Kurosu, pp. 256–65. Lecture Notes in Computer Science no. 5619. San Diego: Springer Verlag.

Nieters, J.E., Ivaturi, S., and Ahmed, I. 2007. Making personas memorable. In *Proceedings of the Conference on Human Factors in Computing Systems*, 1817–23. ACM (ISBN: 978-1-59593-642-4).

Nielsen, L. 2002. From user to character: An investigation into user-descriptions in scenarios export. In *Proceedings of the Conference on Designing Interactive Systems*, 99–104. ACM (ISBN: 1-58113-515-7).

———. 2007. Personas – communication or process? In *Proceedings of the Seventh Danish HCI Research Symposium*, 25–26. http://www.kommunikationsforum.dk/lene-nielsen/blog/personas-communication-or-process (accessed December 15, 2010).

Olsen, G. 2004. Persona creation and usage toolkit. http://www.interactionbydesign.com/presentations/olsen_persona_toolkit.pdf (accessed January 15, 2010).

Pruitt, J., and Grudin, J. 2003. Personas: Practice and theory. In *Proceedings of the 2003 Conference on Designing for User Experience*, 1–15. ACM (ISBN: 1-58113-728-1).

Pruitt, J.S., and Adlin, T. 2006. *The Persona Lifecycle*. San Francisco: Morgan Kaufmann.

Rind, B. 2007. The power of persona. *The Pragmatic Marketer* 5 (4): 18–22.

Robert, J-M., and Brangier, E. 2009. What is prospective ergonomics? A reflection and position on the future of ergonomic. In *Ergonomics and Health Aspects*, ed. B.-T. Karsh, 162–69. Lecture Notes in Computer Science no. 5624. San Diego: Springer Verlag.

Seffah, A., Kolski, C., and Idoughi, D. 2009. Persona comme outil de design de services interactifs: Principes et exemples en e-maintenance. In *Proceedings of IHM 2009*, 333–36. ACM (ISBN: 978-1-60558-461-4).

Spool, J. 2007. Three important benefits of personas. *User Interface Engineering Newsletter*. http://www.uie.com/articles/benefits_of_personas/ (accessed January 15, 2010).

Torrance, E.P. 2004. Un résumé historique du développement des tests de pensée créative de Torrance. *Revue Européenne de Psychologie Appliquée* 54:57–63.

Triantafyllakos, G., Palaigeorgio, G., and Tsoukalas, I.A. 2010 (in press). Fictional characters in participatory design sessions: Introducing the "design alter egos" technique. *Interacting with Computers* 22 (3): 165–75.

Yu, D.J., and Lin, W.C. 2009. Facilitating idea generation using personas. In *Human Centered Design,* ed. M. Kurosu, 381–88. Lecture Notes in Computer Science no. 5619. San Diego: Springer Verlag.

4 Model-Based Framework for Influencing Consumer Products Conceptual Designs

Serge N. Sala-Diakanda and Marcelo M. Soares

CONTENTS

4.1 INTRODUCTION

This chapter seeks to address the problematic communication between design engineers on the one hand, and ergonomists on the other, during the *conceptual* stage of the consumer product design process. The twenty-first century market-driven environment, characterized by increased product differentiation, faster time-to-market, and increased safety requirements offers both a unique opportunity and a challenge. On the one hand, this market has increased the influence of ergonomic factors on product success. The contemporary ergonomist applies information about the human behavior, its skills, limitations, and other characteristics in the design of products, tools, machines, systems, tasks, and environment to ensure productive, safe, comfortable, and effective use by the human being (Sanders and McCormick 1993; Helander 1997). Thus, ease of use, ease of learning, high productivity, comfort, safety, and adaptability are just some of the human factors measures that have established themselves as key determinants of product market acceptance. Furthermore, this phenomenon is extending beyond the traditional consumer product sector. Such is the case with the medical device industry, where aesthetic beauty, error free and consistent control action, and devices' intuitiveness are proving to be powerful drivers of market adoption (Medical Design Technology 2008; Wiklund and Wilcox 2005). On the other hand, however, shorter times to market are also pushing organizations to take more risks during product design. One of the greatest risks incurred is during the conceptual design stage, where a design configuration must be selected from a short list of alternatives. The time constraint in this critical stage may result in design commitments that neglect key human factors considerations, resulting in costly design changes, delayed market introduction and, potentially, loss of market share.

Organizations, therefore, could benefit from the ability to quickly identify the best small set of design alternatives, before proceeding to the subsequent, less flexible stages of the design process. From a human factor standpoint, what such capability implies is the need for the seamless integration of ergonomists in the earliest stages of the design process, principally the conceptual design stage (Cushman and Rosenberg 1991; Harris 1990). Both ergonomists and designers should be able to communicate, without either being required to become an expert in the other's domain. This seamless integration also necessitates a simplified and faster process for performing human factor design analysis and synthesis, as the design is still at the conceptual stage, and is therefore very fluid.

Originally implemented only in the aerospace and defense industry, systems engineering design principles have gained traction in other industries such as health care and energy, where they are used to improve both products and process design. Given the current market environment, the criticality of systematic approaches to product development—such as those offered by systems engineering—can only be expected to grow. Chapanis (1996) analyzes the contribution of the systematic approaches to human factors by the identification and description of the human system interface.

One of the more significant recent developments among systems engineering best practices is referred to as model-based systems engineering (MBSE), also known as model-driven systems development (MDSD). MBSE leverages the power of computer models, and more specifically the expressiveness and rigor of models—in the sense of Baker et al. (2000)—to support a design process that almost always crosses multiple disciplines. Expressiveness refers to a model's ability to express complex information in ways that are easily understood. Rigor, on the other hand, refers to the model's ability to provide clear and unambiguous definitions of behavior, capability, or design. As such, rigor only applies to models that can be simulated. However, for MBSE to be properly implemented, there needs to be a common language to communicate across the many disciplines involved in the product design and development process. The systems modeling language (SysML) was developed for this purpose. We provide a brief introduction to SysML in the next section.

As MBSE was designed to improve communication during product development, an opportunity is here given to ergonomists to increase their influence in the conceptual design stage. In this chapter, we propose a framework for achieving this objective. The first section addresses MBSE, and describes some of the most established, industry-tested MBSE methodologies. We then describe SysML, the language syntax, and discuss how it supports MBSE. The third section of the chapter is dedicated to the SysML-based framework we propose to increase ergonomists' voice in the product conceptual design stage.

4.2 MODEL-BASED SYSTEMS ENGINEERING

MBSE, as defined by Friedenthal, Moore, and Steiner (2008, 17), is the "formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development subsequent life cycle phases." It is therefore a methodology in Martin's (1996) sense, in that it can be characterized as a collection of related processes, methods, and tools used to support the discipline of systems engineering in a "model-based" or "model-driven" context (Estefan 2007). MBSE is believed to provide significant benefits, such as those listed by Friedenthal, Moore, and Steiner (2008) in Table 4.1.

Several MBSE methodologies are currently used in a variety of applications. An overview of the most popular ones is presented here. The interested reader is invited to read Estefan (2007), who provides an in-depth description of each of the methodologies introduced here, as well as some additional ones. These MBSE methodologies largely implement the three most widely used systems engineering processes, shown in Figure 4.1.

TABLE 4.1
MBSE Benefits

- Shared understanding of system requirements and design
  - Validation of requirements
  - Common basis for analysis and design
  - Facilitates identification of risks
- Assists in managing complex system development
  - Separation of concerns via multiple views of integrated model
  - Supports traceability through hierarchical system models
  - Facilitates impact analysis of requirements and design changes
  - Supports incremental development and evolutionary acquisition
- Improved design quality
  - Reduced errors and ambiguity
  - More complete representation
- Support early and on-going verification and validation to reduce risk
  - Provides value through life cycle (e.g., training)
  - Enhances knowledge capture

Source: After Friedenthal, S., et al., *A Practical Guide to SysML: The Systems Modeling Language*, MK/OMG Press, Burlington, MA, p. 17, 2008.

4.2.1 Harmony

Harmony is a tool-independent integrated process for systems and embedded software development (Hoffmann 2010). The process, illustrated in Figure 4.2, is largely based on the Vee model. It consists of a top-down design flow followed by a series of bottom-up integration phases. The end of the process results in a product that can be delivered to the customer. The “system changes” arrow on top of the figure indicates that the entire process should be repeated if a change is required. The first three phases are exclusive to the systems engineering domain, culminating in a set of models that will serve as baselines for subsequent, discipline-specific work to be carried out. These steps have as objectives to (1) identify and determine the required functionality of the product to be developed; (2) identify the different states the product may enter (e.g., standby, on, off, etc.); and (3) allocate the identified functionalities to the subcomponents of the product. Implementation of harmony is done with SysML (Section 4.3).

4.2.2 Object-Oriented Systems Engineering Method

The **object-oriented systems engineering method** (OOSEM) is shown in Figure 4.3. Its objectives are to (1) capture and analyze the necessary information required to specify systems; (2) integrate with object-oriented software, hardware, and other engineering methods; and (3) enable design evolution via reuse of previously used design system components. Table 4.2 provides a descriptive summary of the main activities of the OOSEM.

4.3 SYSTEMS MODELING LANGUAGE

Proper implementation of MBSE necessitates a robust and comprehensive modeling language. SysML is a general purpose modeling language developed to support MBSE. It supports the specification, design, analysis, and verification of systems (Friedenthal, Moore, and Steiner 2008). The language specification, first released in September 2007, is the result of a collaborative effort between members of the object management group (OMG), the International Council on Systems Engineering (INCOSE), and the AP233 Working Group of the International Standards Organization (ISO). SysML is an extension of the unified modeling language (UML)—which itself has proven

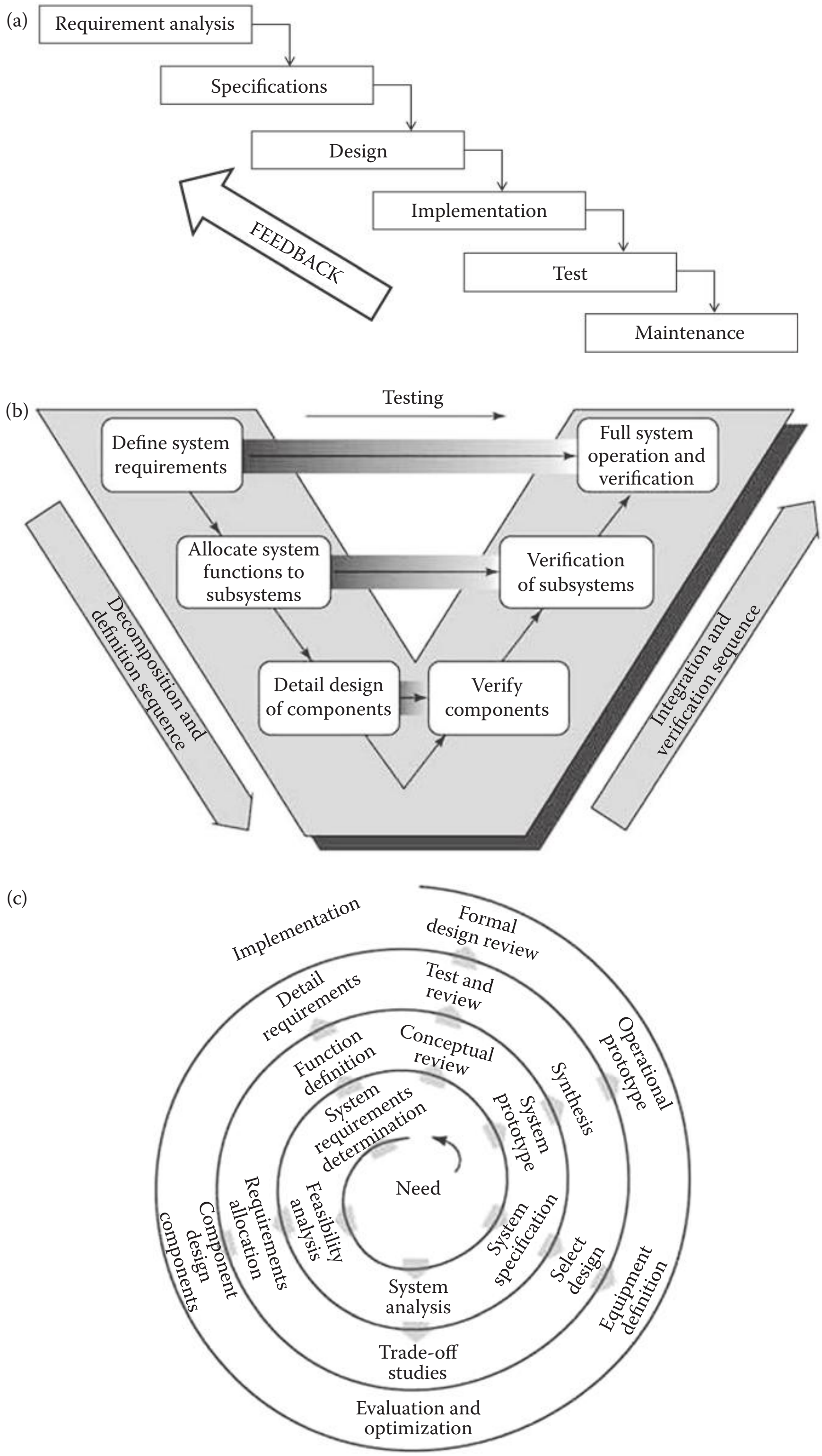


FIGURE 4.1 Waterfall (a), Vee (b), and Spiral (c) systems engineering process models.

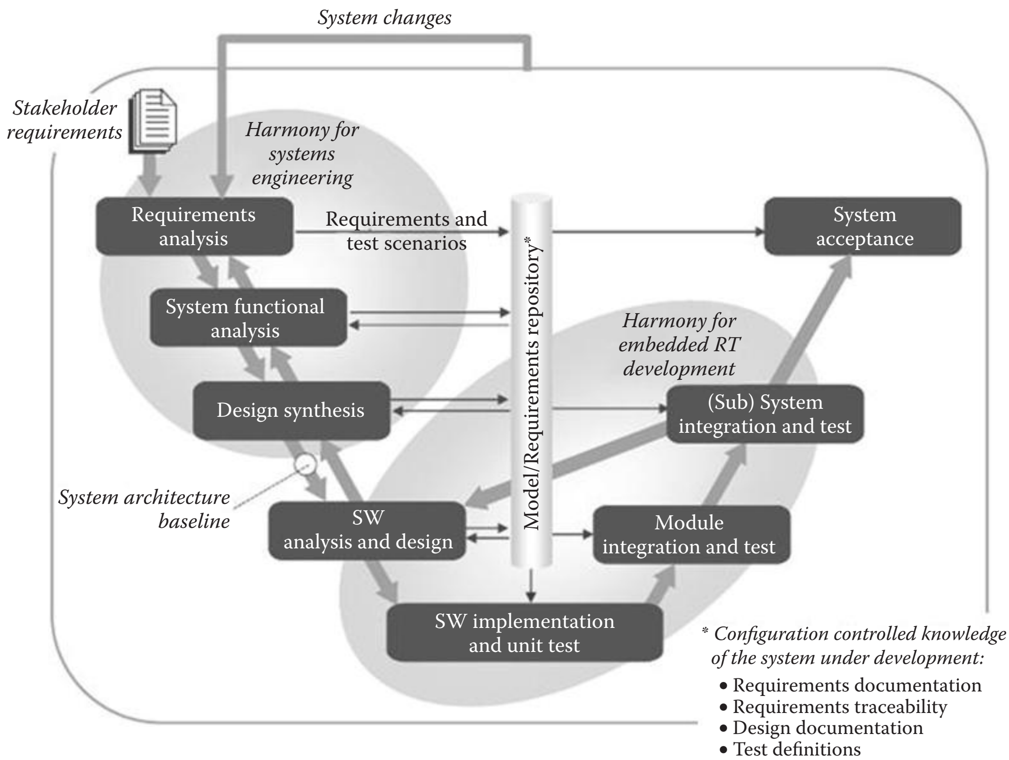


FIGURE 4.2 Harmony systems engineering design process. (From Hoffmann, H.-P., *Model-Based Systems Engineering with IBM Rational Rhapsody*, IBM Corporation, Somers, NY, 2010.)

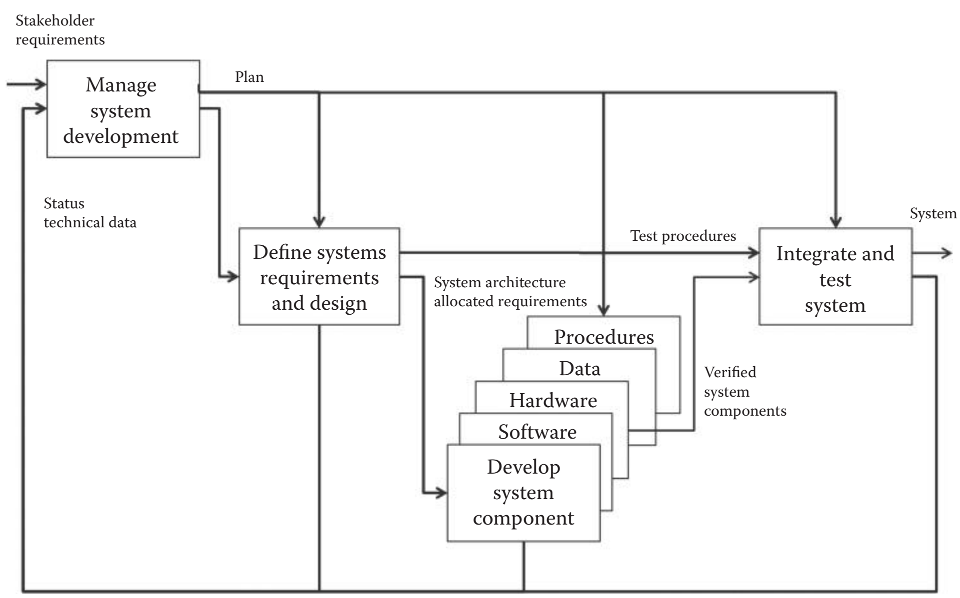


FIGURE 4.3 System development process in OOSEM.

TABLE 4.2
Main Activities of the OOSEM

Activity	Purpose
Analyze stakeholder needs	• Specify an enterprise model, including enterprise current and future subsystems, and enterprise environment (systems expected to interact with the enterprise) • Specify mission requirements in terms of the mission objectives, measures of effectiveness, and top-level use cases
Define system requirements	• Specify the system requirements that support the mission requirements • Capture operational concept for how the system will support the enterprise • Manage requirement change
Define logical architecture	• Decompose and partition system into logical components
Synthesize candidate allocated architectures	• Describe relationship among the physical components of the system, including hardware, software, data, and procedures • Trace components requirements to system requirements
Optimize and evaluate alternatives	• Optimize candidate architectures • Select the preferred architecture • Monitor technical performance measures and identify potential risks
Validate and verify system	• Verify that the system design satisfies its requirements • Validate that the requirements meet the stakeholder needs

Source: From Estefan, J., *Survey of Model-Based Systems Engineering (MBSE) Methodologies, INCOSE Survey of MBSE Methodologies*. INCOSE-TD-2007-003-02, 2007.

very successful in the software engineering community—aimed at supporting systems modeling (Figure 4.4). Figure 4.5 shows the taxonomy of the language. The language specification rests on four dimensions described below: requirements, structure, behavior, and parametric. Models developed in this language may be executed and verified, allowing for the development of good models, in the sense of Baker et al. (2000).

The *requirement dimension*, as its name indicates, is used to capture the stakeholders' requirements for the product. Requirements may capture functions that the product is expected to perform,

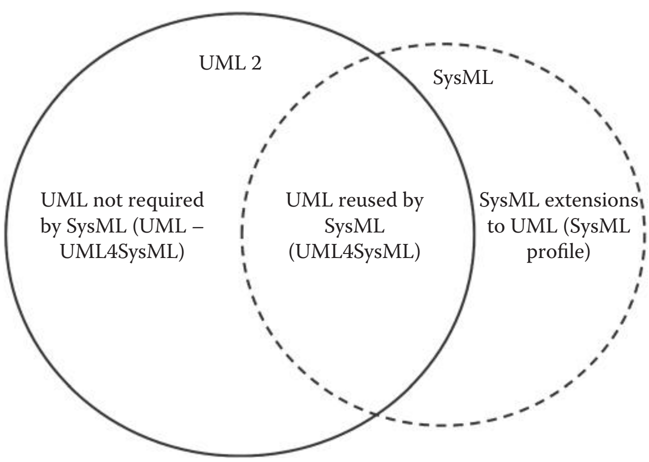


FIGURE 4.4 Relationship between UML and SysML (OMG Systems Modeling Language 2007).

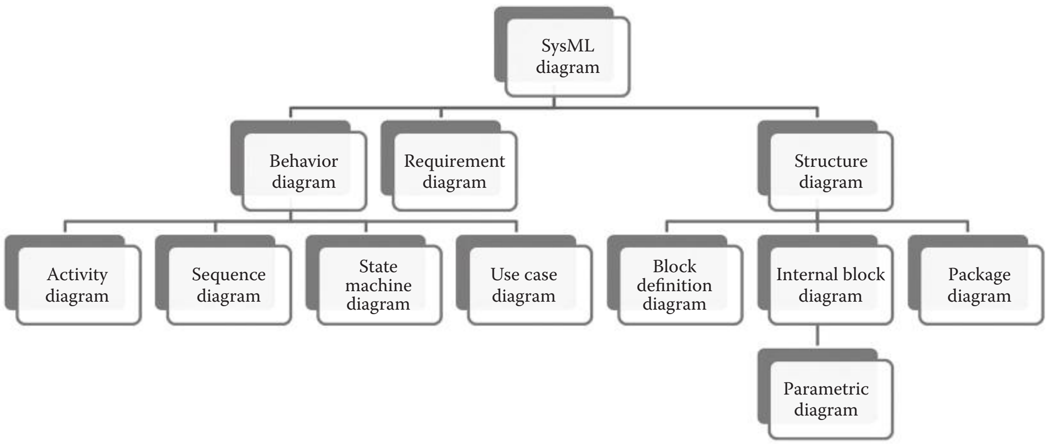


FIGURE 4.5 SysML diagram taxonomy. (From Friedenthal, S., et al., *A Practical Guide to SysML: The Systems Modeling Language*, MK/OMG Press, Burlington, MA, p. 17, 2008.)

or specify any other kind of characteristics the product should observe. The hierarchy of requirements may be captured either through requirements diagrams or in tabular form. A generic requirement diagram is shown in Figure 4.6. It depicts the hierarchy between requirements, as well as the type of relationships between them. Examples of relationships include *containment* (i.e., a requirement is decomposed into multiple requirements), and *derived* (i.e., a *derived* requirement expands on an original requirement). In addition, requirements may be linked to product elements to illustrate how the product is intended to respond to a specific requirement. The *satisfy* relationship is designed specifically for this purpose. In Figure 4.6, product's component C is intended to satisfy requirement Req 1.3.

The *structure dimension* captures the physical architecture of a product by defining all its components and the relationships between them. Whether the product of interest (POI) is physical (e.g., a workstation) or not (e.g., an organization continuous improvement process), the physical architecture captures those components responsible for generating the behavior of the product.

The physical architecture is described through either block definition diagrams (BDD), internal block diagrams (IBD), or package diagrams. An IBD describes the relationship among the different subcomponents of a BDD. Figure 4.7 is one possible high-level descriptive model of the human body. While the BDD identifies the different parts of the human body (and the required number of each part), the IBD captures the relationships among them. However, unlike Figure 4.7, a complete IBD would also describe the nature of the interfaces between each connected part (how the parts are physically connected, and the kind of information exchanged between the connected parts).

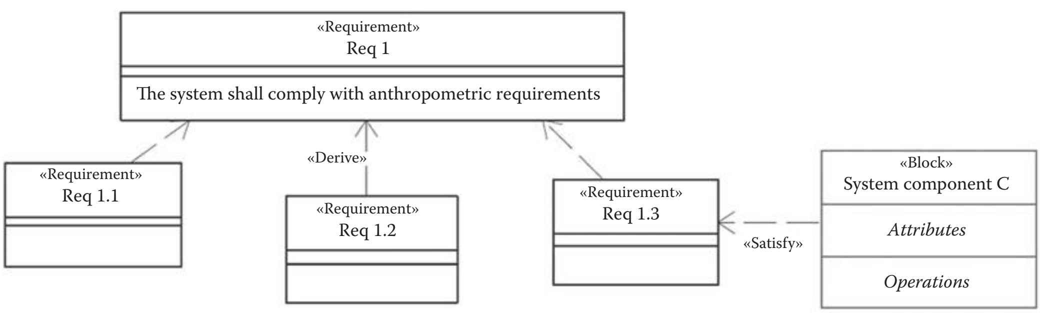


FIGURE 4.6 SysML requirement diagram.

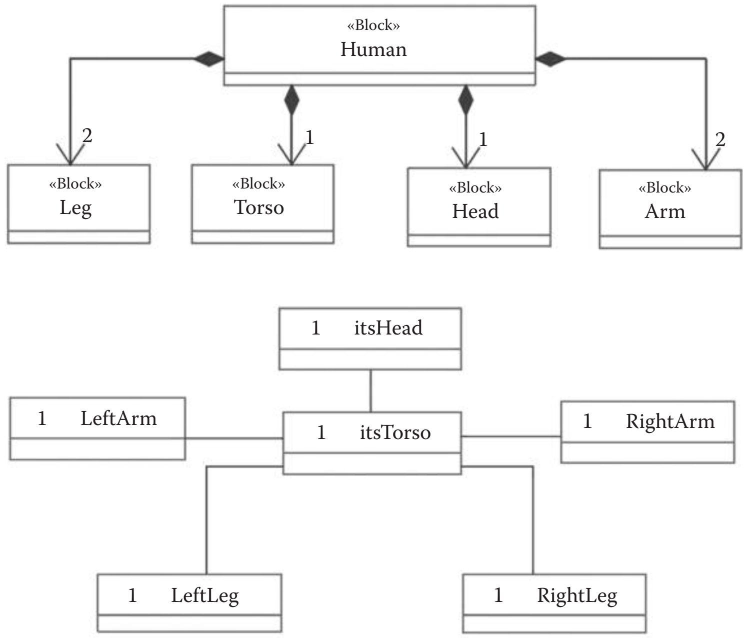


FIGURE 4.7 A block definition diagram (top) and its associated internal block diagram (bottom, interfaces not shown) of the human body.

The *behavior dimension* captures the behavior of the POI. Four different behavioral diagrams—use case (UCD), activity (ACT), sequence (SEQ), and state machine (SM) diagrams—provide a great degree of flexibility for modeling behaviors. UCDs capture the high-level capabilities of the POI (through use cases), and show how the stakeholders interact with it. In addition, UCDs clearly delineate the boundaries of the product, thereby identifying what is part of the product and what is to be part of the environment of the product. Indeed, a critical step in a product concept development process is the determination of its boundaries. Figure 4.8 shows a hypothetical UCD of a piece of machinery that is to be used by a machinist and a repairman. The UCD describes *what* the product is capable of doing, or what a specifically identified element of the environment (an actor) will be able to do with the product. In Figure 4.5, two actors are expected to interact with the machine, indicating that appropriate interfaces will have to be designed in the machine for each of them.

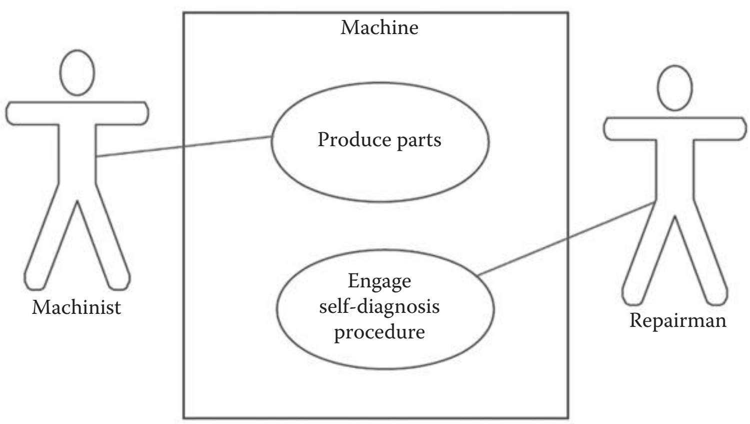


FIGURE 4.8 High-level use case diagram for a manufacturing system.

ACT and SEQ diagrams, on the other hand, describe *how* each of the capabilities identified in the UCD is achieved. There must be at least one ACT for each use case in a UCD. These diagrams describe the specific functions the product will have to perform, and the specific order in which they will have to be performed, in order to exhibit the capability identified by the use case. State machines, on the other hand, identify the different modes the product may be in (e.g., idle, standby, on, off, etc.). ACT and SEQ diagrams are discussed in more detail in the next section.

The *parametric dimension*, through the parametric diagram, is designed to capture constraints on product property values (e.g., mass properties, allowable arm movements), and may serve as a means to integrate a SysML model with engineering analysis software. Through parametric diagrams, a SysML model of a product may be analyzed with domain-specific analysis tools, such as computer-aided design (CAD) software or popular math solvers.

The development of SysML was motivated by the document-intensive (also known as document-centric) nature of systems engineering design processes. Document-centric development has two major shortcomings:

1. It does not enforce constraints between the product's perspectives represented in each document. In other words, each perspective of the product is, in effect, independent from the others. Independence does not support traceability: the ability to trace the impact of a change made in one perspective on the other perspective of the product. As a result, changes that should never have been approved may go undetected until the product is ready for production.
2. It does not support seamless communication between the many disciplines involved in the design process. Document-centric processes are often plagued with a large variety of diagramming techniques and text-based documents. Diagrams and charts may be of a widely known type, such as flow charts, or simply "made-up" by the individual or group submitting it.

The two shortcomings stated above significantly complicate the change management process. Software engineers faced a similar challenge, leading them in the 1990s to develop the general-purpose modeling language known as the UML, to develop software-intensive systems.

Unlike UML however, SysML is designed to cover a wider variety of products, including hardware, software, information, processes, personnel, and facilities (SysMLForum 2010). SysML supports MBSE because it provides a comprehensive set of modeling artifacts to cover the entire systems engineering design process. MBSE methodologies may be fully implemented using SysML, making models effectively the central pieces of communication during the entire design process, and—at least in theory—effectively eliminating the two main shortcomings identified with document-centric processes.

4.4 FRAMEWORK FOR MODEL-BASED SYSTEMS ENGINEERING ADOPTION

For the next generation of consumer products to comply with recognized ergonomics standards while being developed more efficiently, human factors considerations must be incorporated from the earliest stages of the product design process. This section proposes a framework to achieve this objective. The conceptual design stage is where users' requirements are captured, analyzed, and converted into engineering requirements, and where alternative design concepts are investigated, retained, or eliminated. As shown in Figure 4.9, users' requirements are translated to engineering requirements, and users are continuously consulted in subsequent steps of the design process, such as for the selection of the best design alternative.

The criticality of the conceptual design stage is best illustrated in Figure 4.10. The figure indicates that it is during the design concept stage that key decisions regarding budget allocations and other contract commitments are made. Indeed, it is estimated that at the end of this stage,

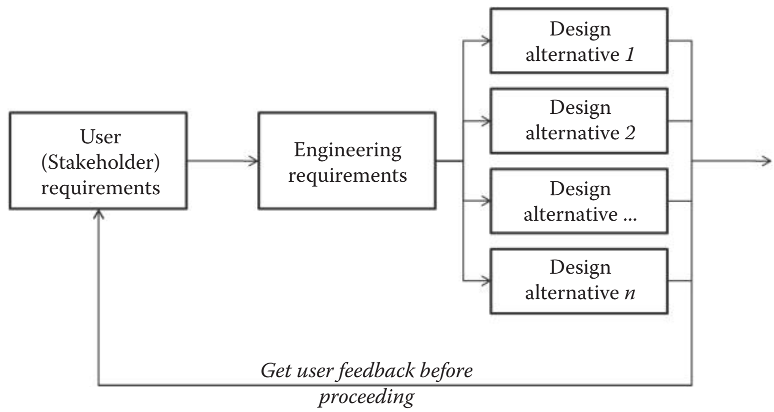


FIGURE 4.9 Users involvement in the earliest stages of product design.

approximately 50% of the projected life-cycle cost for the product is already committed based on engineering design and management decision (Blanchard and Fabrycky 2006). And by the time production is ready to start, 75% of the total cost has already been allocated, rendering any design change a potentially costly endeavor.

This stage is perhaps the greatest (and in some cases, the only) opportunity the diverse disciplines involved in the development of the product have to influence the product design. Yet, this stage is also the most vulnerable to markets' pressures for faster introductions of products. These pressures result in conceptual stages that are fast and dynamic, with changes and decisions made daily, or even hourly. What this implies is that performance measures that may be viewed—more often than not—inappropriately as secondary are given little-to-no weight when identifying the best design alternative. Unfortunately, this is often the case with ergonomic and human factors parameters. Much has been achieved over the last decade to establish ergonomic and human factors as a

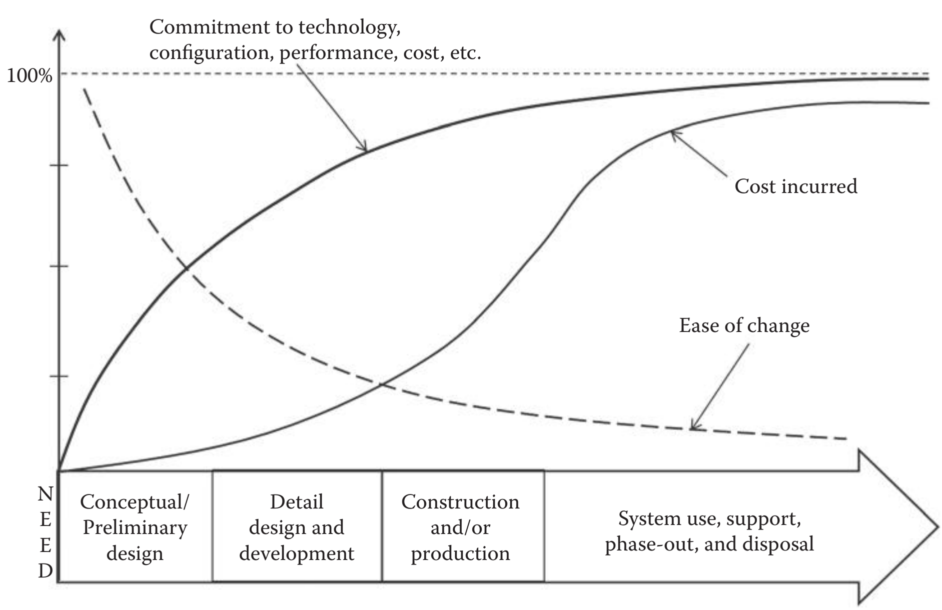


FIGURE 4.10 Life-cycle commitment and cost. (Adapted from Blanchard, B., and Fabrycky, W., *Systems Engineering and Analysis*, 4th ed., Prentice Hall, Upper Saddle River, NJ, 2006.)

"front-line" discipline in the design process. One may cite the establishment of international standards (Seidy and Bubb, 2006) or the Ergonomics Quality in Design document (EQUID) currently being developed by the International Ergonomics Association (IEA), as a helping tool to design products or services that are usable by the widest number of intended users. Yet, much work remains to establish ergonomic and human factors parameters as primary performance measures. The need for means to increase the influence of human factors during conceptual design cannot be overemphasized. The objective of the proposed framework is to facilitate the achievement of this goal.

Some of the most successful attempts to incorporate human factors analysis in the design space include the development of CAD digital human models (DHM), such as SAMMIE and JACK. The primary users of such models are the automotive and aerospace industries. However, although these models have found use in other domains, they are restricted to CAD environments. In addition, DHM tends to be expensive, rendering them inaccessible to smaller developing environments. Embracing a MBSE-SysML-based framework, such as the one introduced here, presents at least two significant advantages:

SysML is domain independent: SysML may be used to develop virtually any kind of consumer products. As SysML continues to gain adoption for the development of increasingly complex products, it seems only natural that ergonomists consider adopting this language to communicate their thoughts, preferences, and findings during the design process, and particularly during the earliest stages.

MBSE via SysML facilitates fast changes: Change management is a significant part of any product development project. During conceptual designs, decisions are made based on incomplete information. Although detailed analyses are not possible at this stage, key decisions *must* be made. Therefore, for ergonomists to play a significant role in conceptual design, they should be able to make recommendations based on the limited information available. Rather than being viewed as the "police" by other design engineers, the ability to perform fast, "quick and dirty" analyses will ensure that ergonomists are properly integrated in this dynamic stage of the product development life cycle.

4.4.1 Systems Modeling Language-Based Framework

The proposed framework centers on the development of SysML digital human models. These SysML DHMs, which we shall now refer to as HUMANSYS, will provide ergonomists with the means to actively participate in the conceptual design process. Figure 4.11 shows a high-level UCD of the framework. HUMANSYS is here a system that will interact with several actors, namely:

Product Design: This actor is the conceptual design of the product. It is an evolving SysML model of the product. ProductDesign uses HUMANSYS to evaluate itself, through the "Evaluate Concept" use case. A key element in the communication between the two models is the definition of their interfaces.

Ergonomist: As the name suggests, this actor represents those ergonomists involved in the project. Ergonomist carries two essentials tasks: First, it evaluates the product design through scenarios stored in HUMANSYS. Second, it is responsible for updating HUMANSYS, by adding scenarios, functionality, and upgrading current functionalities. Ergonomist is also the point entry of human factor users' requirement via its connection with the actual user, as shown in Figure 4.11.

Designer: This actor represents all non-ergonomist parties involved in the design process. Designer also evaluates design concepts. It is, however, primarily responsible for supplying the model to be evaluated, and implementing the recommendations provided by Ergonomist through HUMANSYS.

ISODatabase: For HUMANSYS to possess the necessary human factors functionalities, it will have to communicate with ergonomic and human factor databases, such as ISO 15537, which specify

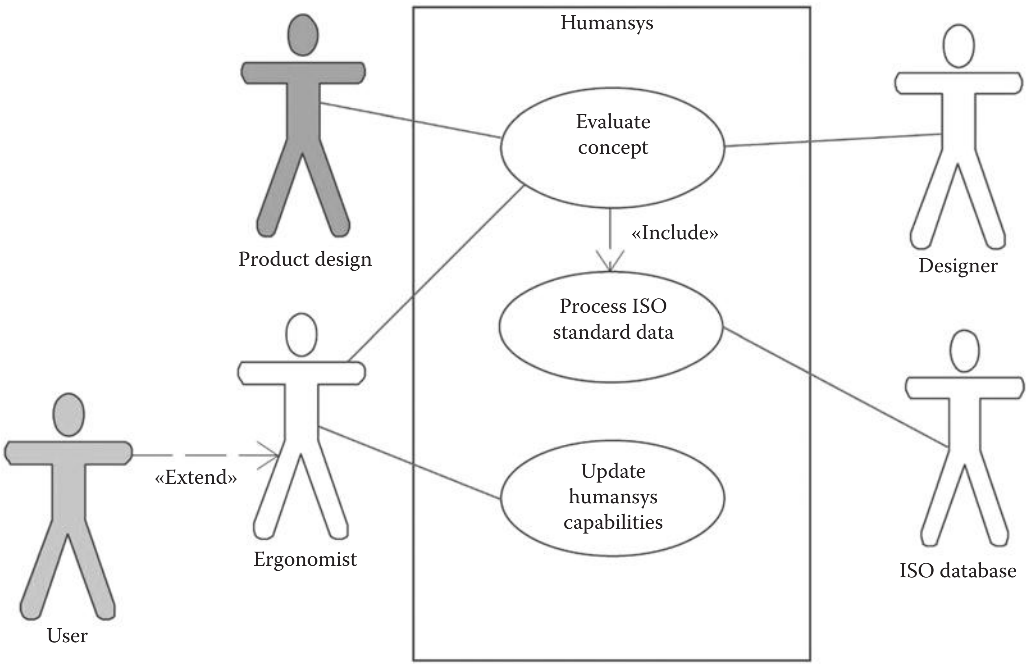


FIGURE 4.11 High-level use case diagram for a SysML human model (HUMANSYS).

how to select the correct person for anthropometric tests. The interaction between HUMANSYS and ISODatabase is captured through the *Process ISO Standards* use case. The *include* stereotype in the figure is to indicate that all evaluation activities will necessitate processing of ergonomics standards.

For the purpose of illustration, suppose HUMANSYS' evaluations of design concepts are anthropometric tests. Then, high-level requirements for HUMANSYS could be formulated such as those shown in Table 4.3. The generic requirements are based on the estimates of the first five body dimensions for British adults aged 19–65 years (Pheasant and Haslegrave 2006). The dataset provides estimates for the 5th, 50th, and 95th percentiles of 36 body dimensions, for both men and women.

4.4.2 Mapping Requirements to Capability

A key contribution of MBSE is change management via the traceability that is maintained between all the models' artifacts. A first traceability requirement is the integration of requirements inside the modeling environment via formal model artifacts, such as requirement diagrams. As opposed

TABLE 4.3
Example of High-Level Stakeholder Anthropometric Requirement for HUMANSYS

1. The system shall assist the designer in the evaluation of the ergonomic worthiness of consumer product concepts
   - 1.1 The system shall evaluate the product design according to stature
   - 1.2 The system shall evaluate the product design according to eye height
   - 1.3 The system shall evaluate the product design according to shoulder height
   - 1.4 The system shall evaluate the product design according to elbow height
   - 1.5 The system shall evaluate the product design according to hip height

to a document-centric approach where requirements would likely be located in a text-based document, separate from the modeling environment, SysML provides a modeling environment where an explicit linkage between requirements and the various aspects of the products satisfying them can be established. This is illustrated in Figure 4.12. The five high-level requirements of HUMANSYS listed in Table 4.3 are linked to "Evaluate Concept," one of HUMANSYS main functionalities. The *trace* relationship is used to establish the link between the requirement artifact and the use case artifact.

4.4.3 Defining HUMANSYS Behavior

As mentioned in a previous section, while UCDs capture the main functionalities of a system (what a system is expected to do), ACT diagrams can be used to demonstrate how those capabilities are to be achieved. ACT diagrams are behavioral diagrams, relating predefined functions that the system must perform to realize a specific use case. We focus here on the "Evaluate Concept" use case, and describe one of the ways that ergonomists could be involved in the conceptual design process. This is captured in Figure 4.13. Their inputs to the product design concept come primarily through HUMANSYS.

The need for evaluation would typically come as a result of a recent revision of the product concept. In this scenario, Designer will submit a request for its model to be evaluated. In typical MBSE fashion, the updated model would have already been connected with HUMANSYS from a previous activity. This request for evaluation will cause HUMANSYS to alert Ergonomist

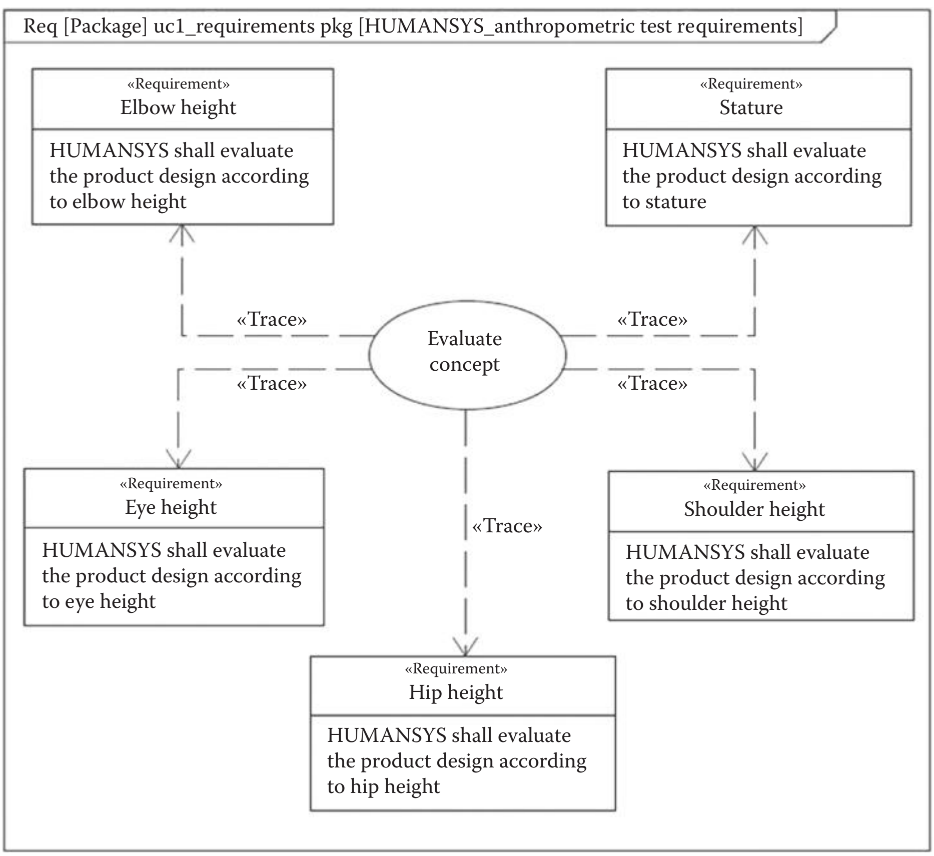


FIGURE 4.12 Traceability of anthropometric requirements to "Evaluate Concept" use case.

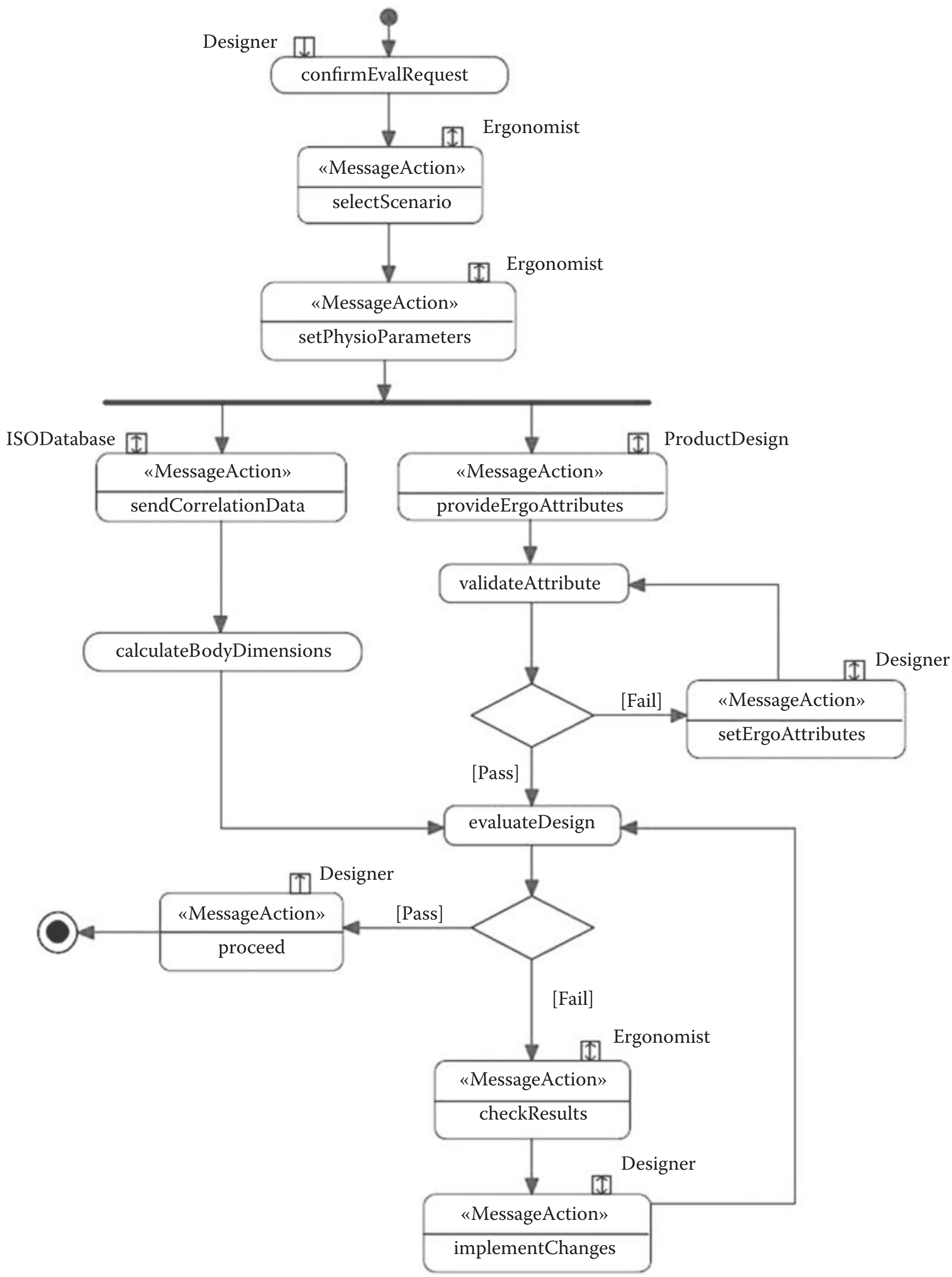


FIGURE 4.13 Example of design evaluation activity carried by SysML human model.

for a scenario selection to perform the evaluation. The alert would be dispatched electronically to the ergonomist's desktop no differently than any other "change" request. Following the selection of a scenario, Ergonomist will then specify the physiological characteristics of the test person (race, gender, etc.). Validation of these characteristics will then lead HUMANSYS to contact both ISODatabase and ProductDesign, the SysML model of the product concept. ISODatabase may then provide correlation data between body measurements (Jurgens, Aune, and Peiper 1990) so that body measurements are accurately calculated. On the other hand, ProductDesign will be requested to provide its ergonomics attributes for evaluation.

Validation may fail, for example, if some attributes that are expected for a particular scenario cannot be found. At this stage, the specific values of these attributes are not requested. HUMANSYS will automatically send a message to Designer in case of validation failure.

Both ergonomics attributes and calculated body dimensions will be used to evaluate the design concept, according to the scenario and the physiological characteristics selected. Successful evaluation will result in an automatic message sent to Designer to proceed with the concept. Otherwise, Ergonomist will be advised to analyze the evaluation outcome and specify some design correction for Designer to implement. This process will be repeated until a satisfactory design is achieved. It is anticipated that this fast, timely exchange will ensure that Ergonomist's inputs are properly integrated in the design process. This process is supported by Chapanis (1996), who emphasizes the iterative, non-linear nature of system development.

The alternative evaluation activities outcomes of Figure 4.13 can be seen individually via SEQ diagrams, such as those in Figures 4.14 and 4.15. While ACT diagrams capture all the possible behavioral scenarios of a use case, SEQ diagrams focus on only one path in the ACT diagram. These diagrams may be used to verify that the intended behavior of HUMANSYS has been properly captured. Both figures indicate that it is the use case "Evaluate Concept" (*:Uc_EvaluateConcept*) behavior that is being analyzed.

A key observation to be made regarding HUMANSYS is that its functions may be grouped in two main categories, as shown in Table 4.4. On the one hand, the first group of functions is geared toward the product, and includes, for example, *evaluateDesign( )*. Obviously, specifically how *evaluateDesign( )* is carried out should be determined during the design of HUMANSYS. Additionally, particular attention should be given to its relevance to the conceptual design stage, a stage defined

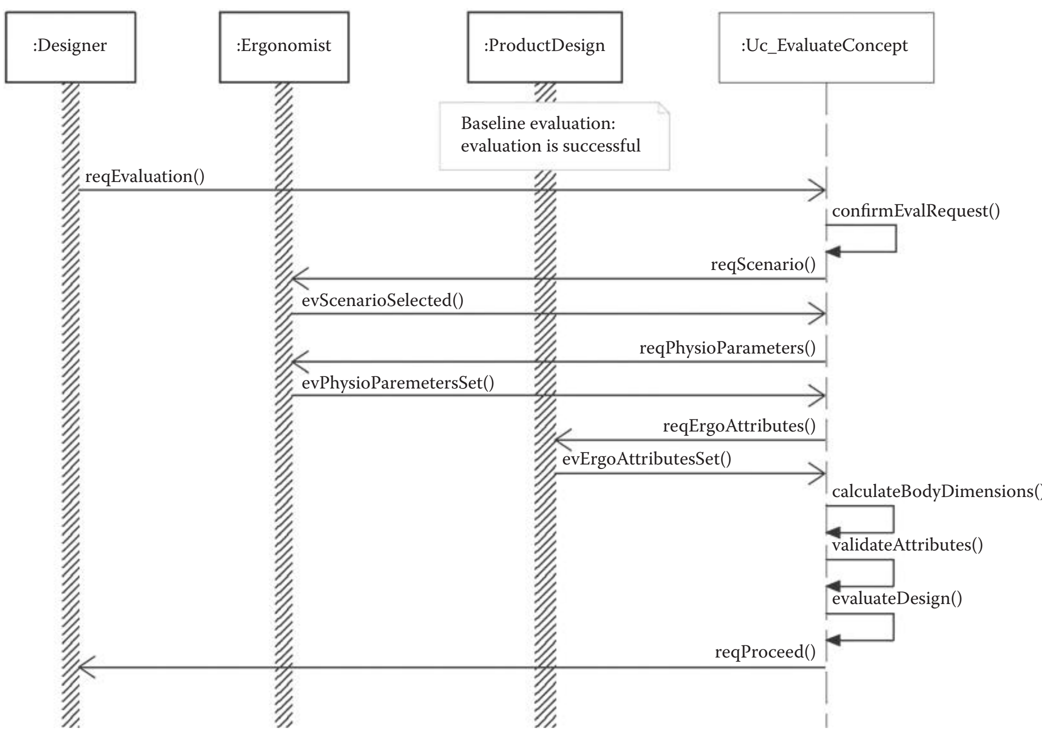


FIGURE 4.14 Sequence diagram of nominal scenario of *EvaluateConcept* use case.

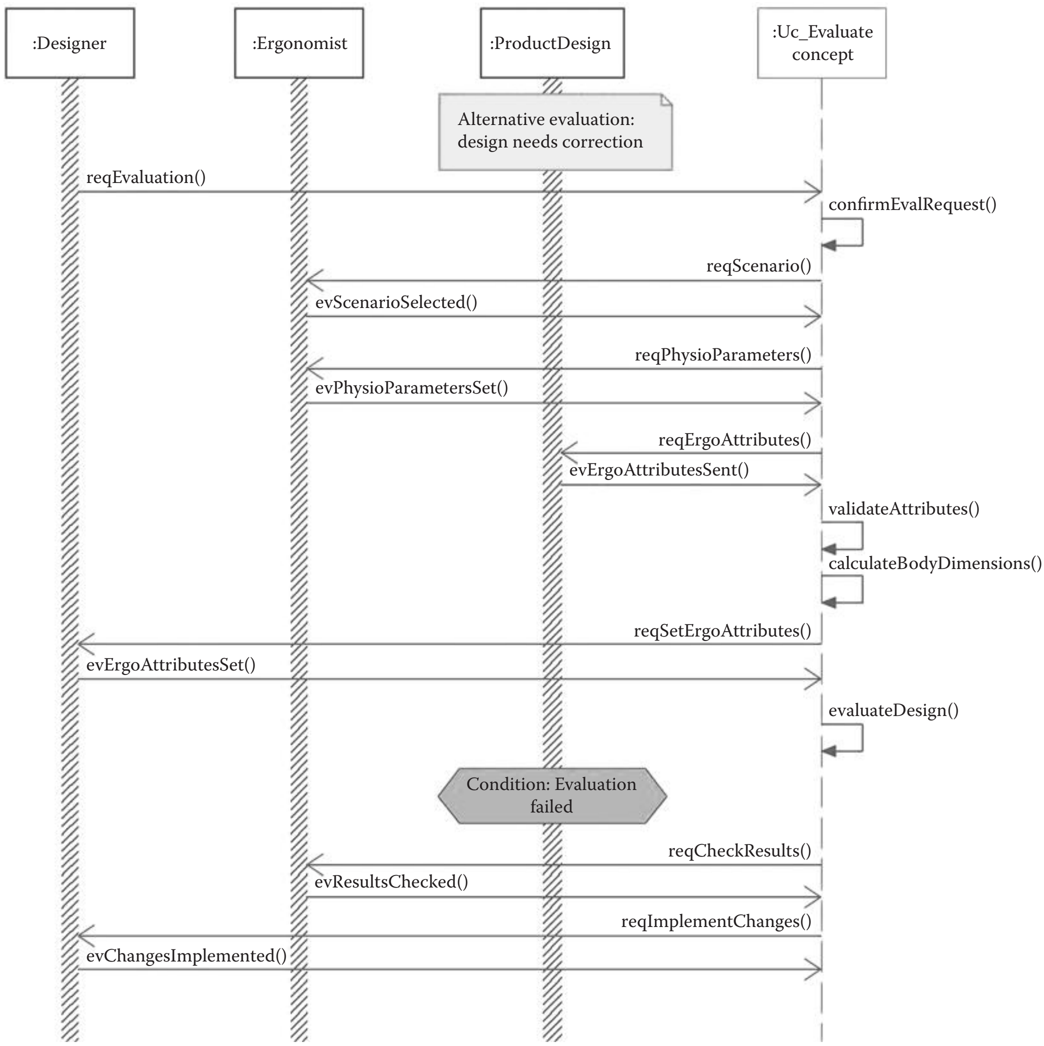


FIGURE 4.15 Sequence diagram of alternative scenario of *EvaluateConcept* use case.

by fast changes and decisions made on incomplete information. The second group, on the other hand, is geared toward maintaining permanent communication channels between ergonomists and designers; *reqSetErgoAttributes( )* for example, belongs to this group.

This second group is the most important from the point of view of increasing ergonomists' role in the conceptual design stage. What this implies is that HUMANSYS should be more than just a DHM. It should be the means of communication between ergonomists and designers.

4.4.4 Defining HUMANSYS Interfaces

The interactions between the different actors—as discussed above—call for the careful formulation of the interfaces required to enable communication. These interfaces can be specified explicitly in SysML using ports. Figure 4.16 is an IBD generated from the ACT and SEQ diagrams developed previously. Four ports are defined:

TABLE 4.4
Product-Oriented and Communication-Oriented Functions

Product-Oriented Functions	Communication-Oriented Functions
reqScenario()	reqEvaluation()
evScenarioSelected()	confirmEvalRequest()
reqPhysioParameters()	reqSetErgoAttributes()
evPhysioParametersSet()	evErgoAttributesSet()
reqErgoAttributes()	reqImplementChanges()
evErgoAttributesSent()	evChangesImplemented()
validateAttributes()	
calculateBodyDimensions()	
evaluateDesign()	
reqCheckResults()	
evResultsChecked()	

Note: Exchanges between HUMANSYS and ergonomist are *product oriented*.

- *pUc_EvaluateConcept*: Any actor or system interacting with HUMANSYS *for the purpose* of evaluating the product design concept, must have this port. In Figure 4.15, this port ensures that Designer, Ergonomist, and ProductDesign can communicate properly with HUMANSYS.
- *pProductDesign*: This port belongs to HUMANSYS for the purpose of communicating with ProductDesign. Similarly, *pDesigner* and *pErgonomist* are there to ensure that HUMANSYS can communicate with Designer and Ergonomist, respectively.

Specifically, what kind of information may be allowed through those ports must also be defined, via the definition of interfaces. The BDD in Figure 4.17 describes six required interfaces necessary to execute the "Evaluate Concept" use case. The interfaces also clearly show

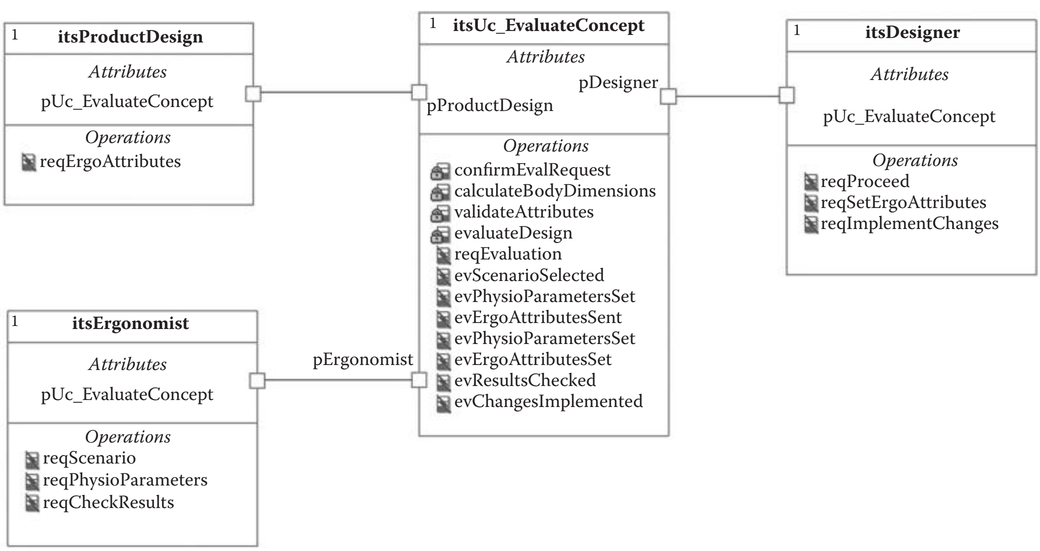


FIGURE 4.16 Internal block diagram of *EvaluateConcept* use case.

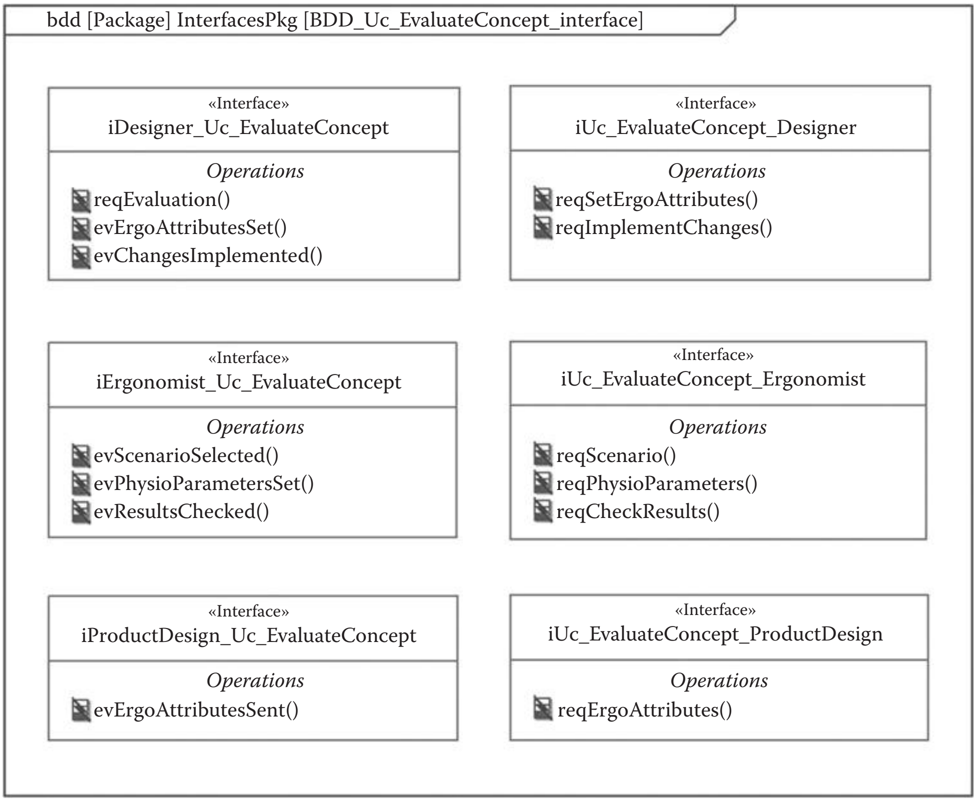


FIGURE 4.17 Block definition diagram of interfaces required for *EvaluateConcept* use case.

the allocations of the operations tabulated in Table 4.4. These interfaces may be looked at in pairs. For example: *iDesigner_Uc_EvaluateConcept* belongs to Designer and its operations consist of requesting evaluations, and responding to requests for changes and attributes setting. The counterpart of this interface is *iUc_EvaluateConcept_Ergonomist*, which belongs to HUMANSYS. Its operations are to request attributes to be set and for design changes to be implemented.

Given the set of HUMANSYS-required functionalities that have been identified, a high-level physical configuration of HUMANSYS may be defined. The physical configuration consists of those internal components that will be responsible for performing the aforementioned functions. The diagram is shown in Figure 4.18. It identifies four main subcomponents:

- *AnalysisModule*: This component is responsible for carrying the evaluation study.
- *DatabaseConnector*: This component is responsible for communicating with ISODatabase.
- *MaintenanceModule*: This component provides access to Ergonomist for HUMANSYS upgrade.
- *CommunicationManagement*: This component is responsible for maintaining communication between Ergonomist and Designer, via HUMANSYS.

4.5 CONCLUSION

Owing to market pressures for faster product introduction, and for more product differentiation, the conceptual design stage has become a rapid, dynamic, and aggressive phase of the product design

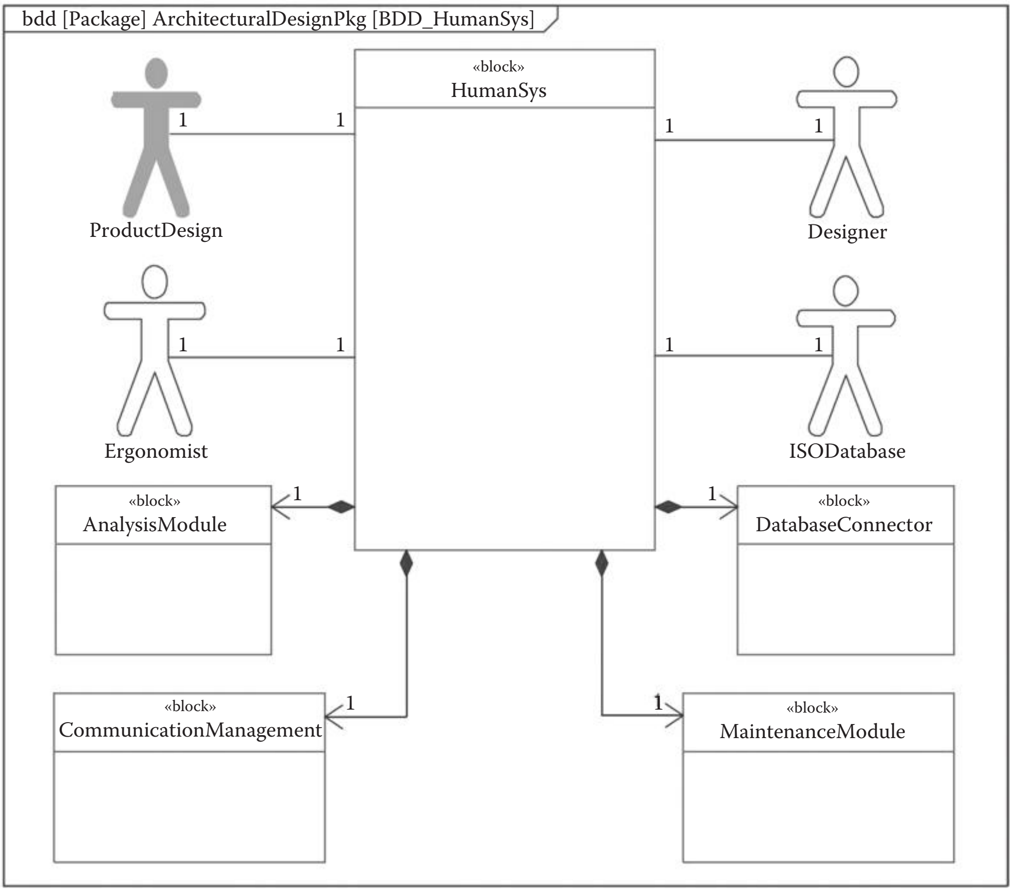


FIGURE 4.18 Block definition diagram of HUMANSYS context.

process. It favors rapid and crude analyses so that the set of design alternatives may be parsed in the shortest time possible. MBSE, and the SysML, are quickly establishing themselves as the change management mechanism of choice in design environments that are becoming increasingly complex. To ensure their relevancy in this critical phase of the design process, ergonomists should consider ways to join this model-centric environment. One such way could be a framework, centered on a SysML DHM, such as the one introduced in this chapter. This SysML-based DHM would not be required to have the complexity of modern CAD DHMs, as it will be focused on the conceptual design stage, where incomplete information is the norm. Yet, its impact on the entire design process, if properly implemented, might prove to be just as—if not more—significant than its CAD counterparts. This is because it will give ergonomists the leverage they need in the most significant phase of the design process.

Much work, however, remains on the framework proposed in this chapter before it can be implemented in the conceptual design environment for consumer products. For example, the proposed SysML-based DHM HUMANSYS was described only at its highest level. Its functionalities must be specified in greater detail before it can be used. Additionally, an important question that was not addressed in this chapter is on the necessary and sufficient level of detail such a conceptual, design-focused DHM should possess. However, this chapter made the case for the need for such a focused, conceptual, design-oriented DHM, and provided, within the proposed framework, a mechanism to establish reliable communication channels between ergonomists and the other parties involved in the product design.

REFERENCES

Baker, L., Clemente, P., Cohen, B., Permenter, L., Purves, B., and Pete, S. 2000. Foundational Concepts for Model Driven System Design. http://www.ap233.org/ap233-public-information/reference/PAPER_MDDE-INCOSE.pdf/view white paper (accessed February 8, 2010).

Blanchard, B., and Fabrycky, W. 2006. *Systems Engineering and Analysis*, 4th ed. Upper Saddle River, NJ: Prentice Hall.

Chapanis, A. 1996. *Human Factors in Systems Engineering*. New York: Wiley.

Cushman, W.H., and Rosenberg, D.J. 1991. *Human Factors in Product Design*. Amsterdam: Elsevier.

Estefan, J. 2007. *Survey of Model-Based Systems Engineering (MBSE) Methodologies*, *INCOSE Survey of MBSE Methodologies*. INCOSE-TD-2007-003-02.

Friedenthal, S., Moore, A., and Steiner, R. 2008. *A Practical Guide to SysML: The Systems Modeling Language.* Burlington, MA: MK/OMG Press, p. 17.

Harris, C.M.-T. 1990. A study in the marketing of ergonomic expertise in the industrial setting. *Ergonomics* 33: 547–52.

Hoffmann, H.-P. 2010. *Model-Based Systems Engineering with IBM Rational Rhapsody.* Somers, NY: IBM Corporation.

Helander, M.G. 1997. The human factors profession. In *Handbook of Human Factors and Ergonomics*, 2nd ed. G. Salvendy, 3–16. New York: Wiley.

Jurgens, H.W., Aune, I.A., and Peiper, U. 1990. *International Data on Anthropometry, Occupational Safety and Health Series Report #65*. Geneva: International Labor Office.

Martin, J.N. 1996. *Systems Engineering Guidebook: A Process for Developing Systems and Products*. Boca Raton: CRC Press.

Medical Design Technology. October 2008. http://www.mdtmag.com (accessed February 8, 2010).

Pheasant, S., and Haslegrave, C.M. 2006. *Bodyspace: Anthropometry, Ergonomics, and the Design of Wor*k. Boca Raton: Taylor & Francis.

Sanders, M.M., and McCormick, E.J. 1993. *Human Factors in Engineering and Design*, 7th ed. New York: McGraw-Hill.

Wiklund, M.E., and Wilcox, S.B. 2005. *Design Usability into Medical Products*. Boca Raton: Taylor & Francis.

5 Smarter Products User-Centered Systems Engineering

Tareq Ahram, Waldemar Karwowski, and Marcelo M. Soares

CONTENTS

5.1 INTRODUCTION

The introduction of user-centered systems engineering (SE) methodology and design principles to design smarter products has been inspired by the theory of smart environments developed in Germany (Bullinger and Scheer 2003; De Jong and Vermeulen 2003; Scheer and Spath 2004). Intelligent and integrated systems have affected industrial and economic growth in many nations. These developments have strengthened the need for emphasizing the role of information and knowledge in smart systems. A revolution sparked by smart systems with its new information society is taking over what has been known as the industrial society (Hauknes 1996). Smart systems design considers qualitative attributes between human–human and human–machine interactions. These considerations include workforce integration (i.e., those who design the system and provide the service) and customers or users (i.e., those who receive and use the product or service). Smart systems design also describes the necessary objects and/or components that constitute intelligent design. During the design process, a designer selects a group of objects and attributes from the design continuum, and assigns a value to each attribute that best fits the objectives and constraints specified by the owner (Kaner and Karni 2007). The resulting smart systems concept is a qualitative and quantitative description of a system in terms of integrated objects representing functionally effective components.

User-centered smart systems (USS) design is characterized by the relationship between knowledge and technology. USS involves the knowledge that is required to deliver the smart product, whether it is invested in the technology of the product or in the service provider (Hulshoff et al. 1998; McDermott, Kang, and Walsh 2001). Knowledge requirements in intelligent systems design and modeling have been arranged into three main categories: knowledge based, knowledge embedded, and knowledge separated (McDermott, Kang, and Walsh 2001). Research has indicated that a knowledge-based smart system, such as teaching aid systems, depends on customer knowledge to deliver intended functionality. This knowledge may become embedded in a product, which makes the service accessible to more people. An example of this is logistics providers, where the technology of package delivery is tracked by radio frequency identification (RFID) embedded in the package and the system that schedules and routes the delivery of packages. It is important to note, however, that the delivery personnel are critical components in both the delivery and pickup stages. Their knowledge is crucial in satisfying customers and providing quality service. The USS approach contributes to systems development processes rather than replaces them. This is achieved by implementing human factors and ergonomics (HFE) principles along with product design and usability engineering (UE) procedures to design user-friendly products and analyze users–system interactions. The following key principles of USS have been identified:

- *Clear understanding of user and task requirements*
  Key strengths of USS design are the spontaneous and active involvement of product or service users and the understanding of their task requirements. Involving end users will improve system acceptance and increase commitment to the success of the new product.
- *Consistent allocation of functions between users and intelligent system*
  Allocation of functions is based on full understanding of customer capabilities, limitations, and task demands.
- *Iterative smart system design approach*
  Iterative smart system design solutions include processing responses and feedback from product or system users after their use of proposed design solutions. Design solutions could range from simple paper prototypes to high-fidelity smart systems mock-ups.
- *Multidisciplinary integration design teams*
  USS design is a multitask collaborative process that involves multidisciplinary design teams. It is crucial that the smart system design team comprises professionals and experts with suitable skills and interests in the proposed system design. Such a team might include end users, smart product handlers (front-stage smart system designers), software integration managers, usability specialists, software engineers (back-stage smart system designers), interaction designers, user experience architects, and training support professionals.

Consumers of a smart product develop knowledge in order to use the system. In knowledge-separated systems, the smart product may be accessible to customers without needing to interact with another human being in the loop. An example of this is the ticketing kiosks at the airport, which have replaced airline representatives. The knowledge of the airline representative is now fully embedded in the ticketing kiosk and integrated with government and airline up-to-date databases. Now a traveler must only have the knowledge to operate the machine. All these components are incorporated and organized in a scheme originating from a generalized definition of a system (Checkland 1981; Nadler and Hibino 1998; Kaner and Karni 2007):

> A system is an organized set of objects which processes inputs into outputs that achieve an organizational purpose and meets the need of customers through the use of human, physical and informatic enablers in a sociological and physical environment.

USS design involves three main components: smart product problem structuring, idea generation, and idea evaluation and selection. This approach helps smart product designers to integrate new connections between various product elements, recognize key processes and elements in the system and recombine them in different ways, identify elements of purpose, and focus on goals. The primary mechanism of customer value creation is divided between customer knowledge, machines, and technological knowledge (McDermott, Kang, and Walsh 2001).

Taxonomies have been used in SE to classify and organize large bodies of information during smart product design and modeling. For example, Gershenson and Stauffer (1999) defined a taxonomy for extracting product design requirements from end users, while Hauge and Stauffer (1993) used taxonomies as a technique for eliciting knowledge from end users. White and Edwards (1995) incorporated taxonomies to specifying requirements for complex systems. Taxonomies can also serve as a basis for knowledge management of USS design and modeling. For example, Gershenson and Stauffer (1999) proposed unique systems taxonomies for four design requirement types: end user, corporate, technical, and regulatory requirements. Karwowski, Salvendy, and Ahram (2009) provided a capstone model for consumer services that supports smart systems design and facilitates the construction of a taxonomy for a design concept, enabling the categorization of the features and attributes contributing to a total system smartness while incorporating both requirements and specifications. Previous research in smart product engineering provided a capstone model for smart product systems design where requirements correspond to the objectives the system intends to achieve and the conditions under which the product is intended to operate.

The capstone model provides inputs to the system design process supplemented by designer intent (Hybs and Gero 1992). Specifications provide information on how the user-centered system is to be built including the system components, and constitute the output of the smart product design process. The hierarchal architecture of USS design processes enables the smart product designer to define the system at several levels, while seamlessly moving from one level of details to another. Goldstein et al. (2002) mentioned that "smart products consist of hundreds or thousands of components." The USS design methodology can cover the entire process of smart systems design while being robust enough to accommodate person-to-person, self-service, and computer-to-computer components. Thus, smart systems design concerns and constraints can be addressed collaboratively while avoiding delays due to conflicts and lack of communication. The USS design methodology draws primarily from user-centered design (Nielsen 1994a, 1994b) and new product development principles of service-oriented architecture (Krafzig, Banke, and Slama 2005).

5.2 SMART PRODUCTS

Several authors have investigated the concept of smartness of consumer products. This section presents a synthesis and summary of the most innovative work that influenced research in this field. Allmendinger and Lombreglia (2005) highlighted smartness in a product from a business perspective. They regard "smartness" as the product's capability to predict business errors and faults, thereby "removing unpleasant surprises from [the users'] lives." The Ambient Intelligence (AMI) group described a vision where distributed services, mobile computing, or embedded devices in almost any type of environment (e.g., homes, offices, cars) are integrated seamlessly with one another using information and intelligence to enhance user experiences (Weiser 1991; Ahola 2001; Arts and de Ruyter 2009). Rapid technological advancements and agile manufacturing created what is called today smart environments. Smart products have to be considered in the context of their environment. Ahram, Karwowski, and Amaba (2010) and Das and Cook (2006) define a smart environment as one that is able to acquire and apply knowledge about an environment and adapt to its inhabitants in order to improve their experience in that environment.

A key issue is the knowledge aspect, as further noted by Mühlhäuser's (2008) references to smart product characteristics that are attributed to future smart environments, i.e., "integrated interwoven sensors and computational systems seamlessly embedded in everyday systems and tools of our lives, connected through a continuous network." In this respect, smarter products can be viewed as those products that facilitate daily tasks and augment everyday objects. In 2007, the AMI identified two motivating goals for building smart products (Sabou et al. 2009):

1. Increased need for simplicity in using everyday products as their functionalities become ever more complex. Simplicity is desirable during the entire life cycle of the product to support manufacturing, repair, and use.
2. Increased number, sophistication, and diversity of product components (e.g., in the aerospace industry), as well as the tendency of the suppliers and manufacturers to become increasingly independent of each other, which requires a considerable level of openness on the product side.

Mühlhäuser (2008) observed that these product characteristics can now be developed due to recent advances in information technology as well as ubiquitous computing that provides a real world awareness in these systems through the use of sensors, smart labels, and wearable, embedded computers. According to Mühlhäuser (2008), product simplicity can be achieved with improved product-to-user interaction (p2u). Furthermore, openness of a product requires an optimal product-to-product interaction (p2p).

Knowledge intensive techniques enable better product-to-product interaction through self-organization within a product or a group of products. Indeed, recent research on semantic web service description, discovery, and composition may enable self-organization within a group of products, thereby reducing the need for top-down constructed smart environments (Chandrasekharan 2004). Smart products also require some level of internal organization by making use of planning and diagnosis algorithms, as stated by Mühlhäuser (2008):

> A Smart Product is an entity (tangible object, software, or service) designed and made for self-organized embedding into different (smart) environments in the course of its lifecycle, providing improved simplicity and openness through improved p2u and p2p interaction by means of context-awareness, semantic self-description, proactive behavior, multimodal natural interfaces, AI planning, and machine learning.

The Smart Products Consortium (SPC) has adopted and modified the definition given in Mühlhäuser (2008). The new definition provides an industry-applicable, life-cycle development methodology with tools and platforms to support the construction of smart products with the emphasis on tangible objects as smart products (i.e., physical products). The SPC defined smart products as follows (Sabou et al. 2009):

> A smart product is an autonomous object which is designed for self-organized embedding into different environments in the course of its life-cycle and which allows for a natural product-to-human interaction. Smart products are able to proactively approach the user by using sensing, input, and output capabilities of the environment thus being self-, situational-, and context-aware. The related knowledge and functionality can be shared by and distributed among multiple smart products and emerges over time.

Major characteristics of smart products are illustrated by comparing their essential features. For example, Maass and Varshney (2008) define six major characteristics (see Table 5.1) for smart products. These characteristics highlight the following major functions:

- Context-awareness: the ability to sense context
- Proactivity: the ability to make use of this context and other information in order to proactively approach users and peers
- Self-organization: the ability to form and join networks with other products

TABLE 5.1
Smart Products Characteristics

Characteristic	Description
Personalization	Customization of products according to buyer's and consumer's needs.
Business awareness	Consideration of business and legal constraints.
Situatedness	Recognition of situational and community contexts.
Adaptiveness	Change product behavior according to buyer's and consumer's responses to tasks.
Network ability	Ability to communicate, integrate, and bundle with other products.
Pro-activity	Anticipation of user's plans and intentions.

Source: Modified from Maass, W., and Varshney, U., *Electronic Markets* 18, 211, 2008.

Mühlhäuser (2008) and the SPC emphasize the fact that smart products should support their entire life cycle. In addition, special care should be devoted to offering multimodal interaction with the potential users, in order to increase the simplicity characteristics of the products.

5.2.1 Systems Engineering Approach for Design and Modeling of Smart Products

SE concepts and principles are an integral part of the contemporary engineered world (Hitchins 2007). Such concepts are also used to create smarter consumer products, produce food, protect human health, enable travel over great distances, and allow for instant and ubiquitous communication. These principles are also used to build houses, design workplaces, and develop an infrastructure on which society relies. The SE principles are used to make services and products cheaper, more functional, and get them to the market faster. Systems engineers apply and integrate concepts and rules derived from mathematics and science to create and apply such principles (Ahram, Karwowski, and Amaba 2010). For example, the energy used to heat, cool, and light residential or industrial dwellings is typically generated hundreds of miles away from where it is used and needs to be transferred over long distances. SE concepts support building smart grid infrastructure and efficient energy distribution networks.

The contemporary SE process is an iterative, hierarchical, top-down decomposition of system requirements (Hitchins 2007). The hierarchical decomposition includes functional analysis, allocation, and synthesis. The iterative process begins with a system-level decomposition and then proceeds through the functional subsystem level all the way to the assembly and program level (see Figure 5.1). Modeling SE process activity is performed using systems modeling language (SysML).

SysML is a general purpose visual modeling language for specifying, analyzing, designing, and verifying complex systems, which may include hardware, software, information, personnel, procedures, and facilities (OMG SysML: http://www.omgsysml.org). SysML provides visual semantic representations for modeling system requirements, behavior, structure, and parametrics, which is used to integrate with other engineering analysis models (Friedenthal, Moore, and Steiner 2008).

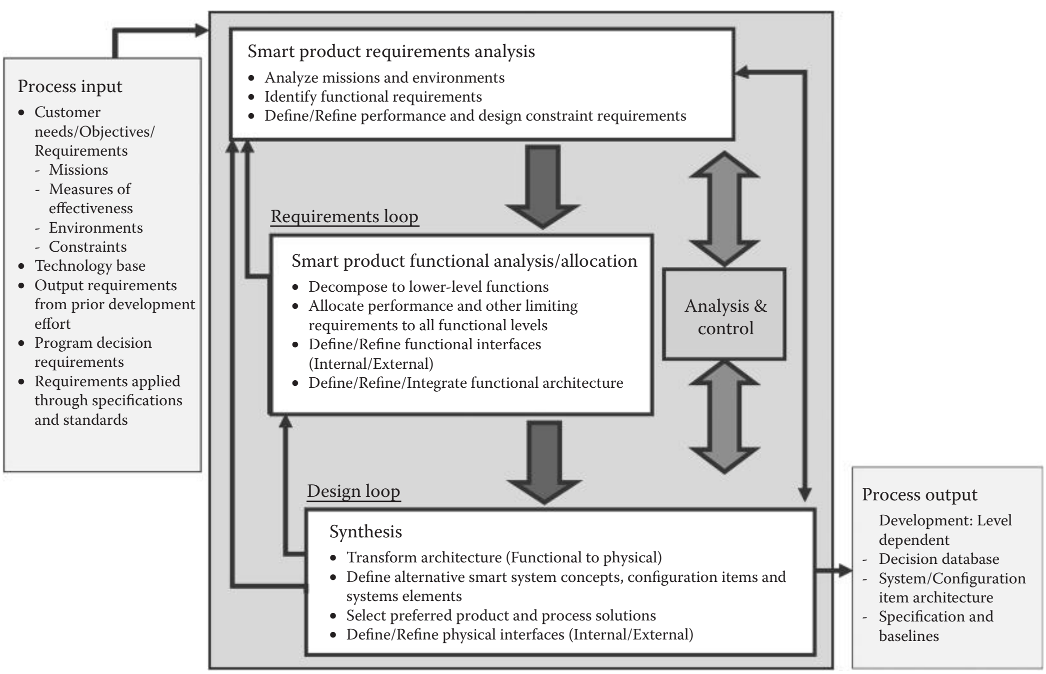


FIGURE 5.1 Framework for smart products SE process. (Modified from Defense Acquisition University, *Introduction to Defense Acquisition Management* (5th ed.), Defense Acquisition University Press, Fort Belvoir, Va, 2001.)

SE teams along with product designers are responsible for verifying that the developed system meets all the requirements defined in the system specification documents (Ahram and Karwowski 2009). The following procedures outline the relevant SE process steps (DAU Guidebook 2001):

- *Requirements analysis*: Review and analyze the impact of operational characteristics, environmental factors, and functional requirements, and develop measures suitable for ranking alternative designs in a consistent, objective manner. Each requirement should be re-examined for consistency, desirability, applicability, and potential for improved return on investment. This analysis verifies that the requirements are appropriate or develops new requirements for the smart product operation.
- *Functional analysis*: Systems engineers and product designers use the input of performance requirements to identify and analyze system functions in order to create alternatives to meet system requirements. SE then establishes performance requirements for each function and sub-function identified.
- *Performance and functionality*: Allocates design requirements and performance to each system function. These requirements are stated in appropriate detail to permit allocation of software, systems components, or personnel. Performance and functionality allocation process identifies any special personnel skills or design requirements.
- *Design synthesis*: Designers and other appropriate engineering specialties develop a system architecture design to specify the performance and design requirements that are allocated in the detailed design. The design of the system architecture is performed simultaneously with the allocation of requirements and analysis of system functions. The design is supported with block and flow diagrams. Such diagrams support:
    - Identifying the internal and external interfaces
    - Permitting traceability to source requirements
    - Portraying the allocation of items that make up the design
    - Identifying system elements along with techniques for its test and operation
    - Providing a means for comprehensive change control management
- *Documentation*: Documentation serves as the primary source for developing, updating, and completing the system and subsystem specifications. Smart product requirements and drawings should be established and maintained.
- *Specifications*: Transfer information from the product or system requirements analysis to system architecture design, and system design tasks. The specifications should assure that the requirements are testable and are stated at the appropriate specification level.
- *Specialty engineering functions*: Participate in the SE process in all phases. They are responsible for system maintainability, testability, producibility, human factors, safety, design-to-cost, and performance analysis to assure that the design requirements are met.
- *Requirements verification*: SE and test engineering verify the completed system design to assure that all the requirements contained in the requirements specifications have been met.

The smart products SE process framework can be used to develop a system in which the user and system synergistically cooperate to conduct the mission (Malone and Carson 2003; Ahram et al. 2009; Karwowski and Ahram 2009).

5.2.2 Benefits of User-Centered Systems Engineering Design Methods and Strategies

User-centered design methods and strategies are concerned with incorporating the user's perspective into the systems development process to achieve usable systems and smarter products or improve existing ones. This section adopts the framework of ISO 13407, where each step in the user-centered design cycle is evaluated with supporting usability methods. Product usability is now widely recognized as one of the critical success factors of an interactive product development process (Fowler 1991; Nielsen 1994a, 1994b; ISO 1997b). Unfortunately, poorly designed, unusable systems exist, which end users find difficult to use. Poor system provisions are costly for an organization and negatively affect the reputation of the smart product vendor. Dissatisfied customers may go so far as to find and choose a substitute vendor with a better system. User-centered design processes and methods help design better systems and increase quality to meet customer expectations. Maguire (2001a, 2001b) has summarized the benefits of following user-centered design principles in systems.

- *Reduced training and support:* User-centered design and usability principles help reduce smart product provider training time and the need for user support. This is of special importance to novel systems since newly introduced smart systems most often require dedicated training and support.
- *Reduced errors:* Poorly designed smart systems significantly increase human error due to inconsistencies, ambiguities, or other interface design faults.
- *Increased productivity:* A smart system employing user-centered design and usability principles will enable users to concentrate on the task rather than the interface in order to operate effectively.
- *Improved user population acceptance:* Most users would be more likely to trust a smart system that provides well-presented information that is easily accessed, increasing end-user acceptance and enhancing customer satisfaction.
- *Enhanced reputation:* A well-designed system will enhance the vendor's reputation in the marketplace and guarantee profitability and customer support for future products and services.

5.3 USER-CENTERED SMART SYSTEM DEVELOPMENT CYCLE

The ISO 13407 human-centered design framework is considered the cornerstone for incorporating different design techniques that can be merged to support a user-centered design process. According to the ISO 13407 standard (ISO 1999), appropriate USS processes are composed of five iterative steps that will guarantee the fulfillment of all requirements in the system design process as follows:

- Planning systems design processes
- Smart product context of use
- Requirements specification
- Integration of design solutions
- Smart systems evaluation and assessment

The five iterative user-centered systems design steps are based on the ISO 13407 framework and are depicted in Figure 5.2. The first step in planning smart system design processes is to communicate smart needs with stakeholders and users to gain agreement on how user-centered design techniques can contribute to the smart system objectives (Karwowski, Salvendy, and Ahram 2009). In addition, the planning process prioritizes smart product requirements and highlights potential benefits gained from including USS activities within the system development process.

5.3.1 Smart Product Context of Use

Smart product context of use defines all aspects of the system's intended usage as well as the user population characteristics (i.e., user profile). Developed systems will be used within a certain set of tasks by users with defined results and goals by performing certain activities. The system will

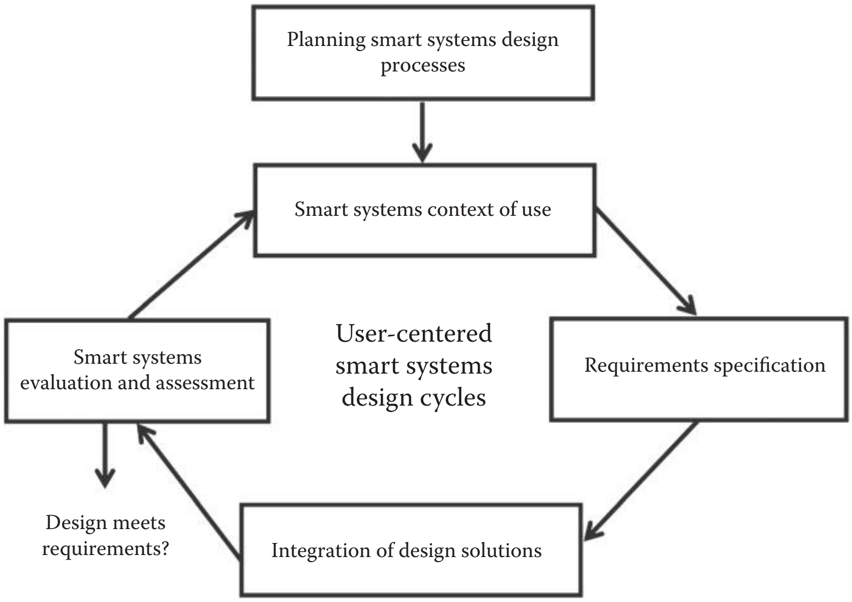


FIGURE 5.2 User-centered smart system (USS) design cycle. (Modified from ISO 13407, *Human-centered Design Processes for Interactive Systems*, International Standards Organization, Geneva, 1999.)

also be used within a known context of physical, environmental, and organizational conditions. Capturing smart product context of use is important for helping to specify user requirements as well as for evaluation and testing. Best practices indicate that effective smart products and systems strongly promote usability, end-user health and safety, and proper understanding of the context of use. Table 5.2 displays several contextual data gathering design methods. Context of use information can be gathered using established structured methods for eliciting detailed information. This information will help facilitate usability evaluation activities, user requirements specification, and system evaluation. Smart product context of use information provides details about the user's profile and characteristics, as well as the task and environment of smart product usage. A description of each step in the user-centered design cycle follows.

5.3.2 Requirements Specification

Requirements specification is one of the most crucial activities of system design and development. The two most common causes of system failure are insufficient effort to identify user requirements and lack of end-user involvement in the design process. ISO 13407 design framework (ISO 1999) provides guidance on specifying end-user requirements and objectives. The framework states that the following elements should be covered in the specification:

- Identification of users and other personnel in the smart product design (e.g., customers, employees, associates, designers, and support)
- Clear statement of the smart product's design and integration goals
- Inclusion of appropriate priorities for the different requirements
- Establishment of measurable benchmarks for which design can be tested
- Acceptance of design requirements by end-users and stakeholders
- Acknowledgment of mandatory or legislative requirements
- Documentation of the requirements and management of changing requirements as the system develops

TABLE 5.2
Summary of Contextual Data Gathering Smart Product Design Methods

Method	Description	Application
Field study user observation (Preece et al. 1994)	Provides data on current system usage and context for system, investigator takes notes on the activity taking place.	When situation is difficult for user to describe in interview or discussion. When environmental context has significant effect on usability.
Identify stakeholders (Taylor 1990)	Identifies all users and stakeholders for the system. Includes all users/stakeholders.	Applied for all systems. For generic systems, it may be supplemented with a market analysis of customers.
Survey of existing users (Preece et al. 1994)	Provides quantitative data from a large number of customers.	Diverse user population. When environmental context has significant effect on usability.
Context of use analysis (Thomas and Bevan 1995; Maguire 2001a, 2001b)	Provides context of use for information design and evaluation.	For all systems.
Diary keeping (Poulson, Ashby, and Richardson 1996)	Record usage over a period of time to understand how future system can support the user.	When there is a current system or when it is necessary to obtain data about current user activity.
Task analysis (Kirwan and Ainsworth 1992)	Analyzing activities or cognitive processes required to do in order to achieve a task.	When it is important to understand task actions in detail as a basis for system development.

5.3.3 Integration of Design Solutions

Design solutions start with innovative and creative ideas through the iterative development process. Low-fidelity prototypes are necessary inclusions to the design life cycle. Human factors professionals and the design team can produce design prototypes. Major problems can be identified before system development proceeds too far along; it is always cheaper and easier to make changes sooner rather than later in the systems design life cycle (SDLC). Systems design methods provide techniques for generating ideas and new system designs through storyboarding, brainstorming, parallel design, and Wizard-of-Oz techniques (Karwowski, Salvendy, and Ahram 2009). The process of iterative design and development requires proper documentation of changes to maintain effective management.

5.3.4 Smart Systems Evaluation and Assessment

Smart products should be evaluated during all design and development stages. Evaluation helps confirm that the intended objectives have been met and provides further information for refining the design. System evaluation starts with low-fidelity prototypes, followed by more sophisticated high-fidelity prototypes. Evaluation and assessment helps improve the smart product as part of the iterative development process and assures that the smart product can be used successfully by the intended users. Smart product evaluation and assessment can highlight problems by either user- or expert-based methods. Expert-based methods can help find weaknesses that may not be revealed by a small number of users. User-based testing is required to find out whether intended users can interact with the product successfully. When running user testing, the emphasis may be on identifying problems and addressing them in the design process.

Innovation in USS is defined as putting creative ideas into actions, while creativity in USS is usually expressed as the generation of ideas toward improving products; creativity and innovation are totally different concepts in smart systems design and modeling (Gurteen 1998; Kaner and Karni 2007). From a user-centered design perspective, creativity involves divergent thinking from the ordinary design perspective. Whereas, innovation involves convergent thinking mixed with creative ideas in systems. McAdam and McClelland (2002) illustrated the vital importance of innovation in engineering, especially smart systems, by indicating that idea generation is a key component of creativity.

5.4 CONCLUSIONS

SE professionals strive to develop new techniques to enhance the value of contributions to multidisciplinary smart product design teams. SE designers challenge themselves to search beyond the traditional design concept of addressing the physical, social, and cognitive factors. This chapter covers the application of user-centered SE design practices based on the ISO 13407 framework to support smart systems design and development. As practitioners collaborate to investigate smart product designs, they concentrate on creating valuable products that will enhance positive interaction.

In conclusion, this chapter stresses the need to follow a user-centered SE approach to smart products design. Products and systems intelligence should embrace a positive approach to user-centered design while improving our understanding of usable, value-adding experience and extending our knowledge of what inspires others to design enjoyable services and products.

REFERENCES

Ahola, J. 2001. Ambient intelligence. *ERICM News* 47.

Ahram, T.Z., and Karwowski, W. 2009. Measuring Human Systems Integration Return on Investment. The International Council on Systems Engineering – INCOSE Spring 09 Conference: Virginia Modeling, Analysis and Simulation Center (VMASC), Suffolk, VA.

Ahram, T.Z., Karwowski, W., and Amaba, B. 2010. User-centered Systems Engineering & Knowledge Management Framework for Design & Modeling of Future Smart Cities. 54th Annual Meeting of the Human Factors and Ergonomics Society (HFES 2010), San Francisco, CA.

Ahram, T.Z., Karwowski, W., Amaba, B., and Obeid, P. 2009. Human Systems Integration: Development Based on SysML and the Rational Systems Platform. Proceedings of the 2009 Industrial Engineering Research Conference, Miami, FL.

Allmendinger, G., and Lombreglia, R. 2005. Four strategies for the age of smart services. *Harvard Business Review* 83 (10): 131–45.

Arts, E., and de Ruyter, B. 2009. New research perspectives on ambient intelligence. *Journal of Ambient Intelligence and Smart Environments* 1: 5–14.

Bullinger, H., and Scheer, A.-W. 2003. Introduction. In *Service Engineering: Entwicklung und Gestaltung Innovativer Dienstleistungen*, ed. H.-J. Bullinger and A.-W. Scheer, 30–45. Berlin: Springer.

Chandrasekharan, S. 2004. The semantic web: Knowledge representation and affordance. In *Cognition and Technology: Co-existence, Convergence, and Co-evolution*, ed. B. Gorayska and J.L. Mey, 153–74. Amsterdam/Philadelphia: Benjamins.

Checkland, P.B. 1981. *Systems Thinking Systems Practice*. New York: Wiley.

Das, S., and Cook, D. 2006. Designing smart environments: A paradigm based on learning and prediction. In *Mobile, Wireless, and Sensor Networks: Technology, Applications, and Future Directions*, ed. R. Shorey, A. Ananda, M.C. Chan, and W.T. Ooi, 337–58. Chichester: Wiley.

Defense Acquisition University. (2001). *Introduction to Defense Acquisition Management* (5th ed.). Fort Belvoir, Va.: Defense Acquisition University Press.

DeJong, J.P.J., and Vermeulen, P.A.M. 2003. Organizing successful new service 7 development: A literature review. *Management Decision* 41 (9): 844–58.

Fowler, C. 1991. Usability evaluation-usability in the product lifecycle. Usability Now! *Newsletter*, Issue 3, Spring, 6–7. HUSAT Research Institute, Loughborough, UK.

Friedenthal, S., Moore, A., and Steiner, R. 2008. *A Practical Guide to SysML: The Systems Modeling Language*. Morgan Kaufmann Publishers. San Francisco, CA: Morgan Kaufmann Publishers; Elsevier Science.

Gershenson, J.K., and Stauffer, L.A. 1999. A taxonomy for design requirements from corporate customers. *Journal of Research in Engineering Design* 11 (2): 103–15.
Goldstein, S.M., Johnston, R., Duffy, J., and Rao, J. 2002. The service concept: The missing link in service design research? *Journal of Operations Management* 20: 121–34.
Gurteen, D. 1998. Knowledge, creativity and innovation. *Journal of Knowledge Management* 2: 5–13.
Hauge, P., and Stauffer, L. 1993. A method for eliciting knowledge from customers. *Proceedings of the Fifth ASME Design Theory and Methodology Conference*, Albuquerque, NM, Sept. 13–16.
Hauknes, J. 1996. Innovation in the Service Economy, STEP Group Storgt, Oslo. ISSN 0804-8185.
Hitchins, D.K. 2007. *Systems Engineering: A 21st Century Systems Methodology*. Chichester: Wiley.
Hulshoff, H.E., Westhof, F.M.J., Kirchhoff, J.J., Kirchhoff, B.A., and Walsh, S.T. 1998. *New Services: Strategic Exploratory Survey of a Dynamic Phenomenon*. Zoetermeer, NL: EIM Small Business Research and Consultancy.
Hybs, I., and Gero, J.S. 1992. An evolutionary process model of design. *Design Studies* 13 (3): 273–90.
ISO 13407. 1999. *Human-centered Design Processes for Interactive Systems*. Geneva: International Standards Organization.
Kaner, M., and Karni, R. 2007. Engineering design of a service system: An empirical study. *Information Knowledge Systems Management* 6: 235–63.
Karwowski, W., and Ahram, T.Z. 2009. Interactive management of human factors knowledge for human systems integration using systems modeling language. *Information Systems Management* 26 (3): 262–74.
Karwowski, W., Salvendy, G., and Ahram, T.Z. 2009. Customer-centered design of service organizations. In *Introduction to Service Engineering*, ed. G. Salvendy, and W. Karwowski, Chapter 9. New Jersey, NJ: Wiley.
Kirwan, B., and Ainsworth, L.K. (eds.). 1992. *A Guide to Task Analysis*. London: Taylor & Francis.
Krafzig, D., Banke, K., and Slama, D. 2005. *Enterprise SOA: Service-Oriented Architecture Best Practices*. Indianapolis: Prentice Hall.
Maass, W., and Varshney, U. 2008. Preface to the focus theme section: 'Smart products'. *Electronic Markets* 18 (3): 211–15.
Maguire, M.C. 2001a. Context of use within usability activities. *International Journal of Human–Computer Studies* 55: 453–83.
Maguire, M. 2001b. Methods to support human-centered design. *International Journal of Human–Computer Studies* 55: 587–634.
———. 2001b. TAQ and SAQ: Pre and post test questionnaires for assessing user acceptance. HUSAT Memo HM1148, June 2001. HUSAT Research Institute, Loughborough, UK.
Malone, T.B., and Carson, F. 2003. HSI top down requirements analysis. *Naval Engineers Journal* 115: 37–48.
McAdam, R., and McClelland, J. 2002. Individual and team-based idea generation within innovation management: Organizational and research agendas. *European Journal of Innovation Management* 5 (2): 86–97.
McDermott, C.M., Kang, H., and Walsh, S. 2001. A framework for technology management in services. *IEEE Transactions in Engineering Management* 48 (3): 333–41.
Mühlhäuser, M., Ferscha, A., and Aitenbichler, E (eds.). 2008. *Constructing Ambient Intelligence*: *AmI 2007 Workshops*, Darmstadt, Germany, November 7–10, 2007: revised papers. Berlin, NY: Springer.
Nadler, G., and Hibino, S. 1998. *The Seven Principles of Creative Problem Solving*. Rocklin, CA: Prima.
Nielsen, J. 1994a. Special Issue: Usability laboratories. *Behavior and Information Technology* 13: 3–197.
———. 1994b. *Usability Engineering*. San Francisco: Morgan-Kauffman.
Poulson, D., Ashby, M., and Richardson, S. 1996. *USER fit: A Practical Handbook on User-Centered Design for Assistive Technology*. Handbook produced within the European Commission TIDE programme USER project. HUSAT Research Institute, Loughborough, UK.
Preece, J., Rogers, Y., Sharp, H., Benyon, D., Holland, S., and Carey, T. 1994. *Human–Computer Interaction*. Reading, MA: Addison-Wesley.
Sabou, M., Kantorovitch, J., Nikolov, A., Tokmakoff, A., Zhou, X., and Motta, E., 2009. Position paper on realizing smart products: Challenges for semantic web technologies. Report by Knowledge Media Institute. http://people.kmi.open.ac.uk/marta/papers/ssn2009.pdf.
Scheer, A., and Spath, D. (eds) 2004. *Computer Aided Service Engineering: Informationssysteme in der Dienstleistungsentwicklung*. Berlin: Springer.
Taylor, B. 1990. The HUFIT planning, analysis and specification toolset. In *Human–Computer-Interaction, INTERACT '90*, ed. D. Diaper, G. Cockton, D. Gilmore, and B. Shackel, 371–76. Amsterdam: North-Holland.

Thomas, C., and Bevan, N. 1995. *Usability Context Analysis: A Practical Guide*. Teddington, Middlesex: National Physical Laboratory.

Weiser, M. 1991. The computer of the 21st century. *Scientific American* 265 (3): 66–75.

White, S., and Edwards, M. 1995. A requirements taxonomy for specifying complex systems. *Proceedings of the First IEEE International Conference on Engineering of Complex Computer Systems* (*ICECCS'95*), Ft. Lauderdale, Florida, 06-November 10, ISBN: 0-8186-7123-8, pp. 373–76.

Section II

Design Process

6 Supply and Demand: Perspectives on Mental Workload with Consumer Products

Mark S. Young and Neville A. Stanton

CONTENTS

6.1 INTRODUCTION

Workload is one of the most widely used concepts in human factors (Flemisch and Onken 2002). Yet it is also one of the most nebulous concepts, with numerous definitions and dimensions associated with it. Moreover, research in this area has a tendency to focus on complex, often safety-critical systems (e.g., transport, process control). This chapter takes us beyond the usual suspects of humans in control, and looks instead at how mental workload (MWL) affects everyday interactions with consumer products, and what lessons we might apply to product design.

We begin by reviewing the concept of MWL, providing some definitions and typical examples of research. Next, we examine the relationship between MWL and usability—which provides a foundation for the subsequent section on MWL in consumer products. Examples are provided of research on products where MWL has been or may be an issue in their use. As a related area, we then take a step aside to consider how MWL can affect auxiliary consumer factors of product choice and preferences, such as instructions or functionality. Finally, we return to the more typical literature on MWL in order to contrast consumer product issues with those of more complex systems, and offer some conclusions about the role of MWL in product design.

6.2 WHAT IS MENTAL WORKLOAD?

MWL is one of those peculiar constructs that has intuitive appeal, but is surprisingly difficult to agree on a definition. There are, however, commonalities among the various interpretations in the literature, which can help shed light on the topic.

An analogy is often made with physical load, in that there may be two components—stress (i.e., task demands) and strain (impact on the human; cf. Schlegel 1993). Even the international standard on MWL (ISO 10075 2000) is heavily dependent on the stress/strain dichotomy in its terminology. In fact, this division serves as a useful basis for classifying the design implications of MWL—by product complexity or external resources and support (Stanton 1998), as we shall see later. Demands (stress) can have multiple facets, such as time pressure or task complexity. There may also be different kinds of resources available, in other team members, technological support, or skill and experience. Finally, the trade-off between these may have different effects (strain) on the human—as measured by the different objective (task performance, physiological) and subjective metrics in the literature (see e.g., Bevan and Macleod 1994).

So, when we consider that stress is comprised of multiple demand factors, and strain has multiple effects depending on the resources available, explaining MWL in terms of demand/resource balance offers an attractive and parsimonious view of this otherwise multidimensional construct. Resources, in this sense, often refer to attentional resources (e.g., Wickens 2002)—thus MWL becomes a product of the resources available to meet task demands (Welford 1978). In an attempt to bring all this together and provide a global definition of MWL, Young and Stanton (2005, ch. 39-1) suggested that MWL reflects "the level of attentional resources required to meet both objective and subjective performance criteria, which may be mediated by task demands, external support, and past experience." In this definition, the level of attentional resources is assumed to have a finite capacity, beyond which any further increases in demand are manifest in performance degradation. At the same time, the investment of resources is a voluntary and effortful process (Hockey 1997), so performance can be maintained at the cost of individual strain or vice-versa. Performance criteria can be imposed by external authorities, or may represent the internal goals of the individual. Examples of task demands are time pressure or complexity, as we have already seen, and support may be in the form of peer assistance or technological aids. Finally, past experience can influence MWL via changes in skill or knowledge.

One contribution to MWL that may often be neglected is the physical demands of the task. ISO 10075 is not alone in considering physical load itself to be a component of MWL—seminal metrics for quantifying MWL (e.g., the NASA-TLX; Hart and Staveland 1988) include physical factors in their dimensions. But where physical workload should normally be kept to a minimum, we now know that MWL should be optimized in order to achieve best performance (Wilson and Rajan 1995). In the complex, safety-critical systems where MWL research is usually most pertinent (such as aviation—e.g., Wickens, Gempler, and Morphew 2000; rail—e.g., Pickup et al. 2005; or driving—e.g., Young and Stanton 2004), both underload and overload can be equally detrimental to performance. The question is, do these recommendations apply to the design of consumer products?

6.3 MENTAL WORKLOAD AND USABILITY

Another one of ergonomics' overused and oft-misunderstood buzzwords, usability has popularly become somewhat synonymous with ease of use. From that perspective, it would seem appropriate for MWL to be a factor in usability—since ease might easily be associated with low MWL. However, this extrapolation of the term "usability" is part of the underlying misunderstanding, for it is not simply a case of being easy to use. In ISO 9241 (1998), usability is defined as comprising "effectiveness, efficiency and satisfaction" (see also Bevan 2001, for a commentary). Nielsen (1993) adds learnability as a key component, which refers to the gradient of the learning curve, or the speed in which the novice can reach criterion performance. Thus, usability is more about performance standards in achieving a goal, rather than simply the ease with which it is achieved. In Young and Stanton's (2005) definition, performance criteria are one of the determinants of MWL—so we already have a link between usability and MWL. But let's explore the concept in more detail.

Both learnability and efficiency have been associated with MWL. It stands to reason that minimizing MWL will improve learnability and performance (Lin, Choong, and Salvendy 1997). Moreover, efficiency—essentially the speed/accuracy trade-off—provides the link between MWL and usability (Bevan and Macleod 1994; Keinonen 1998; Jordan 1998). The implication is that MWL can be used as a measure of efficiency, based on the idea that invested effort (i.e., strain) should not be excessive in order to achieve criterion performance (Bevan and Macleod 1994). In other words, users should not have to try too hard in order to achieve a satisfactory performance. Similarly, high MWL can reduce efficiency by increasing the likelihood of errors (Jordan 1998). This is particularly important when the MWL is associated with an additional task, secondary to something more safety-critical (such as using in-car devices when driving). Thus, while Keinonen (1998) points out that ISO 9241 discusses the consequences of too low as well as too high MWL, the overriding implication here is that MWL should be minimized for usability. We'll come back to this issue later.

If MWL is therefore a determinant of usability, it is logical that any usability metric should include some measure of MWL, not just performance (Bevan and Macleod 1994). Earlier, we mentioned some objective measures of MWL, including physiological techniques, and some have tried to apply these to an assessment of usability—albeit with limited success. For instance, Nickel et al. (2002) used heart rate variability (HRV, a widely used measure of MWL) to evaluate the usability of software in a control room. While HRV might be a good indication of strain, it turned out not to be sensitive enough for a practical usability assessment. Similarly, Faggart and Andre (2005) investigated the possibility of using eye movements and pupil dilation—another reliable indicator of MWL—in a web page usability evaluation. While there was a trend toward an effect associated with usability problems, the variability in how users dealt with the problem meant that the data were not conclusive.

It seems, then, that while MWL and usability may be indirectly related (Keinonen 1998), they are by no means significantly overlapping. To be fair, though, this makes sense when considering that performance efficiency (for which MWL might be the most direct determinant) is but one factor in the overall usability equation. If we take a task-based approach, MWL issues have typically been associated with continuous, dynamic tasks such as driving (e.g., Young and Stanton 2004), whereas consumer products are usually associated with more discrete or static activities. Again, we raise the question as to whether the typical attitudes toward MWL management in complex systems (i.e., optimization instead of minimization) can apply to consumer products. With this in mind, let us examine some specific research on MWL with consumer products.

6.4 MENTAL WORKLOAD AND CONSUMER PRODUCTS

We are not the first to note that our modern lives are becoming more information-rich—and consequently complex: Norman (1988) provides his usual sage commentary on the memory demands of everyday life. While technology purports to make our lives easier, a multitude of PIN codes, postcodes and telephone numbers conspire against our memory capacities to actually make things more difficult. Indeed, it is the very technology itself that often leads to these problems. Take the widespread use of automated telephone menu systems (such as those used by many customer service lines) as a case in point. Poor design of these systems can overload the user and lead to errors (as discussed by Jones and Marsden 2006).

One of our guiding principles in product design must therefore be to reduce the memory demands on users wherever possible (Bonner 1998; Cushman and Rosenberg 1991; Wickens et al. 2004). Technology should be exploited to support the user and provide "knowledge in the world" (cf. Norman 1988), instead of relying on the user's own stored knowledge. Instead, products are actually becoming ever more complex, with increased functionality perversely matched by a trend to reduce the number of buttons on devices (Bonner 1998). Such complexity and—in many cases, over-functionality (Maguire 2004)—weighs down the demands side of the MWL equation, with precious little support for resources (Stanton 1998). Stanton and Baber (1998) explain this in terms of decision options, whereby the functionality embedded within the system is said to afford the user with alternative actions toward a goal. With excessive functionality, there are too many available actions, and hence increased MWL.

To counter this problem, a simple solution would be to strip down the functionality to the bare essentials. But this might disadvantage more skilled users, who interact with products in different ways from novice users (Keinonen 1997), and naturally reduce their decision options through their enhanced mental model of the system (Stanton and Baber 1998). This could allow them to exploit the added functions without becoming overloaded. Maguire (2004) suggests a compromise for technological gadgets, whereby a basic product is bought from new, with the option to download added capabilities or modules as the user's needs dictate. This is appealing since it facilitates customization just on the user's requirements, and avoids wasted functionality.

A more pragmatic approach might be to facilitate learnability by helping the user to develop accurate mental models (Bonner 1998) or making the interface compatible with existing mental models (cf. Wickens, et al. 2004). The point is to reduce the decision options and so minimize the possibility of overload and confusion. Under this approach, users are guided through the interaction by applying some relatively simple interface design initiatives, such as signposting (Bonner 1998). As an illustration, Figure 6.1a–c shows three steps through the adjustment of the time setting on a quite inexpensive digital watch. At each step, an arrow on the LCD points out to the user which button should be pressed next.

Based on the discussion so far, it is unsurprising that much of the existing research in this area has been concerned with technological gadgets such as mobile phones or personal digital assistants

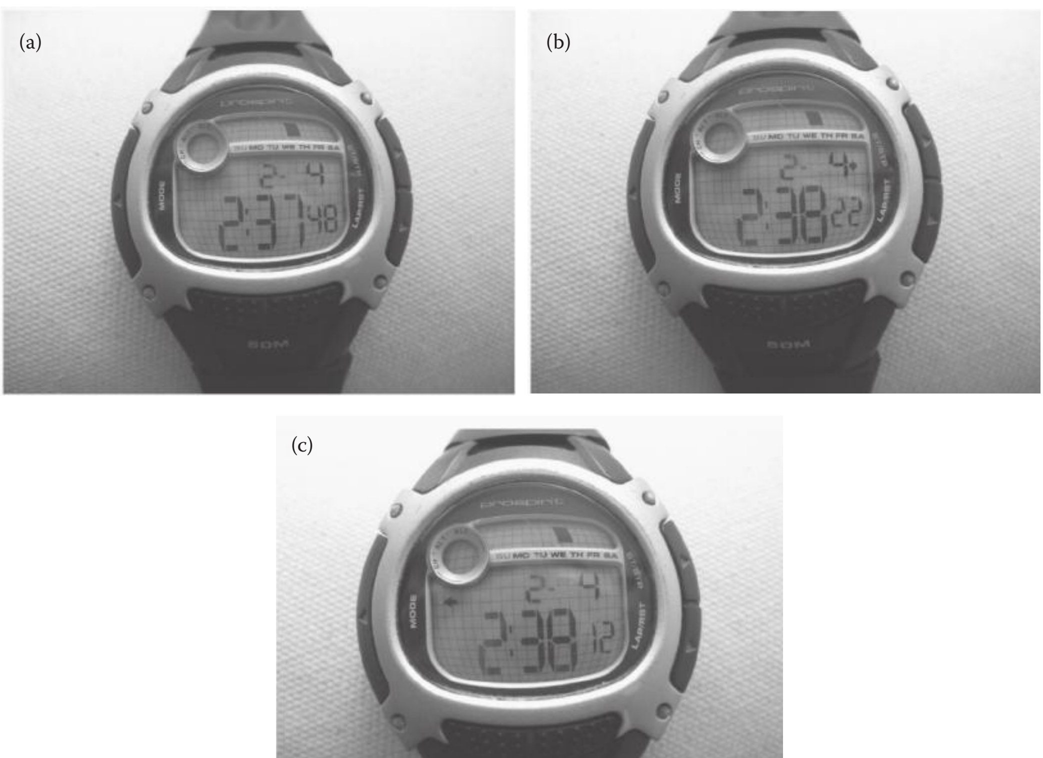


FIGURE 6.1 Three steps in setting time on a digital watch—note how the watch guides the user through the interaction by arrows on the display pointing to the next button press.

(PDAs). Thus, we move on in the next section to case studies on this particular family of consumer products.

6.4.1 Using Consumer Technology

We have already mentioned how technology can actually make our lives more, rather than less complex, and it is largely this inexorable technological evolution that has fed the growth in MWL research within the ergonomics community. The rise of ubiquitous computing (cf. Stanton 2001) has moved technology out of the workplace and into the home, from e-books (Kang, Wang, and Lin 2004) to interactive television (Han et al. 2005), putting more onus on the human's cognitive powers to deal with the world around them. Sometimes, this everyday technology unnecessarily increases functionality and MWL—the interactive television study (Han et al. 2005) did increase satisfaction but at the cost of increased MWL. Other research suggests that television viewers do not want a customizable interface or intelligent formatting of channel types—the whole point is to watch television, and so they just end up channel surfing (Crandall, Klein, and Hoffman 2006). The implication is to avoid technology for its own sake. But convergent technological evolution in products does promise to streamline some areas of our lives, one example being the electronic PDA, which is bidding to replace not just traditional diaries, but also to become integrated with mobile phones, GPS devices, and even laptop computers. Being miniature computers themselves, PDAs offer much more functionality than simple pen-and-paper. Indeed, PDAs have even been used as a substitute for traditional pen-and-paper quizzes in a university classroom, demonstrating improved efficiency without any significant increase in MWL or satisfaction (Segall, Doolen, and Porter 2005).

However, with this added functionality comes a much more complex interface, as a lot of information is packed onto a small screen (Brewster 2002). To complicate matters, PDAs typically have very few buttons (cf. Bonner 1998), relying instead on touchscreen technology through the graphical user interface (GUI) for data input. A related study on portable media players (Chen et al. 2005) found that different button configurations for the solid interface did not affect subjective usability or MWL; rather the user's pre-existing mental models were a much stronger influence on performance. For the GUI, while the use of standard desktop metaphors offers some compatibility with user mental models and hence reduces MWL (cf. Cushman and Rosenberg 1991), the demand for screen space can mean that "soft" (i.e., touchscreen) buttons end up smaller than optimal, which increases MWL (Brewster 2002). Using enhanced auditory feedback for soft button-presses is a relatively simple design intervention that improves usability and reduces workload, and is so powerful that it can actually compensate (within limits) for smaller button sizes (Brewster 2002). Indeed, feedback is so crucial for maintaining the flow of interaction that system delays as low as one second can disrupt the user's thought patterns (Golightly 2004).

Since PDAs and similar devices are marketed as mobile technology, it is expected that people will use them concurrently with other activities such as walking or even driving. One test of efficiency is therefore whether such gadgets truly can be used on the move without affecting performance or MWL. Unsurprisingly, studies show that both MWL and serious usability problems increase when people are asked to perform other motor activities while working with the device (Brewster 2002; Kjeldskov and Stage 2004). However, an attempt to design an interface for one-handed operation met with little success, as users dismissed the opportunity, and neither MWL nor usability was affected (Jacobsson et al. 2000).

Of course, a similar class of product, which is almost invariably used concurrently with everyday activities, is the mobile (cell) phone. The main debate in recent years surrounds use of the phone while driving, and there is now a strong consensus of opinion that using a mobile phone when driving degrades driver attention and performance. Phoning and driving significantly increases driver workload and slows reactions (Alm and Nilsson 1995; Haigney, Taylor, and Westerman 2000), even to the point of being worse than drunk driving (Strayer, Drews, and Crouch 2003). Furthermore, there is evidence that reaction times increase regardless of whether the phone is hand-held or hands-free (Consiglio et al. 2003; Lamble et al. 1999). These findings imply that the effects are due to cognitive competition in time-sharing or divided attention, rather than the simple physical interference from handling the phone (cf. Haigney and Westerman 2001).

More recently, we have seen the problem of sending text messages while driving become a prevalent issue (e.g., Drews et al. 2009). Composing a text message is a visually and mentally demanding task, especially before the advent of predictive text—which reduces performance times, button presses, and MWL (Dunlop and Crossan 2000). Nevertheless, the arrival of texts, alerts, and other messages from our mobile applications have the potential to disrupt our daily lives—particularly if they arrive at inopportune moments, such as when driving. Research into adaptive interfaces has been applied to try and manage the arrival of these messages using a "physiologically attentive user interface" (PAUI; Chen and Vertegaal 2004). The PAUI monitors the heart rate and EEG of the user as measures of MWL, and regulates notifications according to whether the user is at rest, moving, thinking, or busy.

6.4.2 Learning to Use Consumer Products

When it comes to the kinds of technological gadgets we have been discussing, many users often cannot wait to switch them on and try them out. Consequently, the chunky instruction booklet that typically accompanies such products is cast aside as too daunting a prospect. It seems that what cannot be learned in a 30-second sound bite is not worth learning. Indeed, in an ideal world, a product's interface would be so transparent as to provide enough "knowledge in the world" (cf. Norman 1988) and be so compatible with user mental models that the user can operate it by intuition alone—thus negating the need for an instruction book and all the consequent mental effort in learning to use it.

Needless to say, such an ideally usable product has not been developed as yet. While simply playing with a product may be a good way to learn its basic functions, by avoiding the handbook many users are missing out on the deeper functionality, and so may end up using the device in an inefficient or limited way (Maguire 2004). It is certainly true that good user guidance can improve learnability and performance with the product (Lin, Choong, and Salvendy 1997). However, we have already noted that over-functionality can unnecessarily increase MWL in use, thus the user who operates the product on a "need to know" basis (i.e., just learning the functions they need) could paradoxically be improving their performance in the long run. As is the truism with marketing, perhaps the extra functionality is something users never realized they needed until it was offered. Nonetheless, there does seem to be a growing trend in consumer gadgets to supply an overview crib sheet in addition to the standard handbook, which provides the essential information just to get the user started with the device. Coupled with an increasing capability to offer online tutorials and intelligent help systems, perhaps we are getting closer to achieving the instruction-free product. Good instructions may help (cf. Lin, Choong, and Salvendy 1997), but ultimately an ideal interface is the way to manage MWL and performance (cf. Norman 1988).

While an intuitive interface may be a laudable goal for technological devices, there are other categories of consumer products that will inevitably incur some mental effort on the part of the user—and which would not be feasible without instructions. The case in point here is flat-pack furniture—another modern trend in the home, since self-assembly products are cheaper and easier to transport, but present a host of potential ergonomic challenges. Richardson and Jones (2005) specifically looked at the usability of self-assembly from the perspective of the user's mental demands. Again, the product's instructions have been brought into focus, since many are developed for a global market and are hence dependent purely on illustrations, with minimal verbal advice. It might be thought, then, that the format of the instructions would be a significant factor in the MWL involved in assembly, but Richardson and Jones (2005) in fact found that the structure of the product itself had a greater influence. Task factors, such as the number of fastenings, the number of unique assemblies required in construction, and the number of symmetrical planes in the product, all had a bearing on mental demands. Interestingly, while the number of components per se affected perceived complexity, it was not a factor in objective thinking time. The authors explained that the other task factors increased cognitive demands due to the spatial transformations involved with achieving the task goals. So, as with the gadgets discussed earlier, it seems that the "interface" here is a key driver in product MWL.

6.4.3 Choosing Consumer Products

Taking another step further back in the product life cycle, consumers are faced with a dizzying array of choice when shopping for the types of products we have discussed here. Televisions, mobile phones, PDAs, digital cameras—the list is endless, and for most consumers it can be a bewildering and difficult decision to make. The MWL involved in choosing from the available options is an important factor in the eventual decision, as information overload can lead to poor decisions being made (Owen 1992; Owen and Haugtvedt 1993). MWL is thus a key area of research in consumer psychology.

There appears to be little difference in the construct of MWL between consumers who are choosing the products, and the actual users of those products. Consumer MWL is still a multidimensional construct, comprised of objective and subjective factors, and involving both stress and strain elements (Cooper-Martin 1994). A great deal of the stress (task) factors is largely to do with the number of product alternatives available and the attributes or features associated with those products (Keinonen 1997; Owen 1992). The main problem for consumer MWL seems to be the amount of choice available. Ironically, efforts to help consumers make their decisions by providing more information (e.g., through product labeling) actually just exacerbate the overload problem (Owen and Haugtvedt 1993). Product choice notwithstanding, the MWL and decision process is very much dependent on context as well—bigger decisions (such as buying a car) will inevitably involve more complex and drawn-out thought processes (Cooper-Martin 1994). Moreover, the expertise of the consumer affects how the decisions are made—experts preferring to search the technical attributes of the product, while novices rely on non-functional attributes such as brand or price.

The whole consumer decision process is therefore based on minimizing MWL (Cooper-Martin 1994; Crandall, Klein, and Hoffman 2006)—if there are too many product options, consumers will just reduce the alternatives to basic factors such as price or brand. It is interesting to note that even here we have strong parallels with MWL in more complex dynamic systems. Bainbridge (1978) observed that expert users will often revert to a novice operational strategy when the demands of the situation increase. Apparently, consumers do the same—when demands are too high (i.e., too much product choice), decisions revert to the fundamental attributes of the products in order to increase efficiency. The synergies between MWL research in complex, safety-critical systems and the more everyday domain of consumer products are reviewed in the closing section of this chapter.

6.5 CONCLUSIONS: THE SPECIAL CASE OF CONSUMER PRODUCTS?

We started this chapter by suggesting that most MWL research in human factors and ergonomics has been focused on complex, dynamic, safety-critical systems such as transport or process control. Indeed, many of the developments and definitions in MWL have been born out of such applications. Nevertheless, in reviewing the implications of MWL for usability in consumer technology, it is clear that many of the principles and issues are applicable across domains. In keeping with ISO 10075, MWL in consumer products is very much a product of stress (task demands from product complexity) against strain (user effort, which can be ameliorated by support, help functions, or user guidance).

The question remains, though, as to whether the design implications for more complex systems hold true for consumer products. In the continuous dynamic world of safety-critical systems, it has long been recognized that MWL should be optimized for best performance (Wilson and Rajan 1995)—the operator should be neither overloaded nor underloaded. Demands and resources between operator and technology need to be balanced in order to maintain the overall performance of the system. However, consumer products are a discontinuous activity domain—their use can be interrupted without any real consequence for performance (Sauer and Rüttinger 2007). Given that many of the concerns raised in this chapter are to do with the complexity of consumer products, we may well be led to conclude that MWL should, in fact, be minimized in these cases. The use of consumer technology is often a secondary activity (e.g., in-vehicle information systems while driving, using the PDA or mobile phone while walking), and so it perhaps makes sense to reduce MWL in order to make the interaction as efficient as possible.

We know that underload causes performance problems in cases such as transport (e.g., Young and Stanton 2002), and more often than not this is associated with automation. To counter this, there is a growing consensus that pilots, drivers, etc., should be supported by technology, rather than replaced—particularly where the task involves higher-level decision-making elements, rather than low-level control activities (Young, Stanton, and Harris 2007). Sauer and Rüttinger (2007) argued that problems of automation in applied domains (such as trust, complacency, skill degradation, or "out-of-the-loop" performance) are not applicable or are of less concern with consumer products, because operation of consumer products is largely a matter of these low-level control actions. They supported this position with evidence that automation for control integration (such as a vacuum cleaner that automatically adjusts its power for optimum efficiency) led to better performance than automation for perceptual augmentation (e.g., a dust sensor on the vacuum cleaner to inform the user of cleanliness levels). In other words, these results are in stark contrast to work-related automation in dynamic settings, where perceptual augmentation is recommended over control automation.

Thus, many consumer products do not—and, indeed, should not—impose the levels of MWL experienced by drivers, pilots, nuclear power station operators, etc. (Crandall, Klein, and Hoffman 2006). In fact, we arguably have a special case for MWL in consumer products, for in order to maximize effectiveness and efficiency in choosing, learning, and using them, MWL should apparently be minimized as far as possible. However, that is not the end of the story, since we know that usability is comprised of one more element—satisfaction. While the absence of difficulties in use would undoubtedly increase satisfaction, there is also some pleasure to be gained from being engaged with a product (cf. Jordan 1998). Moreover, we feel that Sauer and Rüttinger (2007) have been optimistic in considering that issues such as skill degradation do not apply to consumer products. A brief thought experiment may help to illustrate our point. Consider a situation, which may well have happened to you, in which you need to contact a friend or colleague, whose details are stored in your mobile phone. However, you forgot to charge the battery this morning, and it will not power up for even a few seconds. You have some loose change that you could use in a payphone, but do you remember the number you need to dial? Probably not, since it is unlikely you refer to the actual number when dialing from your mobile phone—you simply key in the relevant name from the contacts list. While it may be laudable to support performance with "knowledge in the world" in this way (cf. Norman 1988), just as with automation in other areas, you can become dependent on the technology and forget the core information necessary to complete the task.

So, managing MWL with consumer products is a complex balancing act of supply and demand—the demands of the product against the supply of user resources. In the main, MWL should be minimized in terms of the tasks that consumers are expected to perform—especially where use of the product is secondary to a more safety-critical activity such as driving. Likewise, resources should be maximized—not necessarily through instructions or handbooks, but through demonstrations, online tutorials, and primarily through intelligent and intuitive interface design. Automation support can be useful in executing these discrete, non-critical tasks, but only for low-level operations where users do not become solely dependent on the technology for critical information, otherwise we may see skill degradation in the same way as for complex systems. Knowledge in the world is good, but users can still be tripped up if (and when) the technology fails.

Just as a final endnote, we have reviewed issues of MWL in consumer choices—where information overload can actually lead to poor purchase decisions. Usability may not be just about ease of use, but reducing MWL can certainly improve product choice, learnability, and performance in use. So, maybe this is somewhere that ergonomics can offer a unique selling point in a crowded marketplace. If MWL is about stress and strain, then instead of offering users more information or too much functionality, the consumer need only know one thing: this product makes your life easier.

REFERENCES

Alm, H., and Nilsson, L. 1995. The effects of a mobile telephone task on driver behaviour in a car following situation. *Accident Analysis and Prevention* 27 (5): 707–15.

Bainbridge, L. 1978. Forgotten alternatives in skill and work-load. *Ergonomics* 21:169–85.

Bevan, N. 2001. International standards for HCI and usability. *International Journal of Human-Computer Studies* 55:533–52.

Bevan, N., and Macleod, M. 1994. Usability measurement in context. *Behaviour & Information Technology* 13:132–45.

Bonner, J.V.H. 1998. Towards consumer product interface design guidelines. In *Human Factors in Consumer Products*, ed. N. Stanton, 239–58. London: Taylor & Francis.

Brewster, S. 2002. Overcoming the lack of screen space on mobile computers. *Personal and Ubiquitous Computing* 6 (3): 188–205.

Chen, D., and Vertegaal, R. 2004. Using mental load for managing interruptions in physiologically attentive user interfaces. In *Proceedings of ACM CHI 2004 Conference on Human Factors in Computing Systems*, eds. E. Dykstra-Erickson and M. Tscheligi, 1513–16. Reading, MA: ACM Press.

Chen, S.C., Chen, C.H., Chan, C.Y., and Wang, Y.C. 2005. Designing interaction compatibility between graphic and solid user interfaces – a case study of a portable media player. In *HCI International 2005 – Proceedings of the 11th International Conference on Human-Computer Interaction*, Las Vegas, July 22–27. Mahwah, NJ: Lawrence Erlbaum (CD-ROM format).

Consiglio, W., Driscoll, P., Witte, M., and Berg, W.P. 2003. Effect of cellular telephone conversations and other potential interference on reaction time in a braking response. *Accident Analysis and Prevention* 35 (4): 495–500.

Cooper-Martin, E. 1994. Measures of cognitive effort. *Marketing Letters* 5 (1): 43–56.

Crandall, B., Klein, G., and Hoffman, R.R. 2006. *Working Minds: A Practitioner's Guide to Cognitive Task Analysis*. Cambridge, MA: MIT Press.

Cushman, W.H., and Rosenberg, D.J. 1991. *Human Factors in Product Design*. Amsterdam: Elsevier.

Drews, F.A., Yazdani, H., Godfrey, C.N., Cooper, J.M., and Strayer, D.L. (2009). Text messaging during simulated driving. *Human Factors* 51 (5): 762–70.

Dunlop, M.D., and Crossan, A. 2000. Predictive text entry for mobile phones. *Personal Technologies* 4:134–43.

Faggart, D., and Andre, T. 2005. Determining potential metrics of eye-movement data to aid in the usability problem identification process. In *HCI International 2005 – Proceedings of the 11th International Conference on Human-Computer Interaction*, eds. E. Dykstra-Erickson and M. Tscheligi, Las Vegas, July 22–27. Mahwah, NJ: Lawrence Erlbaum (CD-ROM format).

Flemisch, F.O., and Onken, R. 2002. Open a window to the cognitive work process! Pointillist analysis of man-machine interaction. *Cognition, Technology and Work* 4 (3): 160–70.

Golightly, D. 2004. Dealing with delay. *The Ergonomist* 414:4.

Haigney, D., and Westerman, S.J. 2001. Mobile (cellular) phone use and driving: A critical review of research methodology. *Ergonomics* 44 (2): 132–43.

Haigney, D.E., Taylor, R.G., and Westerman, S.J. 2000. Concurrent mobile (cellular) phone use and driving performance: Task demand characteristics and compensatory processes. *Transportation Research Part F* 3:113–21.

Han, J., Choi, W., Song, C., and Kim, S. 2005. Design of a multi-modal for effective screen cursor movements. In *HCI International 2005 – Proceedings of the 11th International Conference on Human-Computer Interaction*, eds. E. Dykstra-Erickson and M. Tscheligi, Las Vegas, July 22–27. Mahwah, NJ: Lawrence Erlbaum (CD-ROM format).

Hart, S.G., and Staveland, L.E. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Human Mental Workload*, eds. P.A. Hancock and N. Meshkati, 138–83. Amsterdam: North-Holland.

Hockey, G.R.J. 1997. Compensatory control in the regulation of human performance under stress and high workload: A congnitive-energetical framework. *Biological Psychology* 45: 73–93.

ISO 10075. 2000. *Ergonomic Principles Related to Mental Work-Load*. Brussels: CEN.

ISO 9241-11. 1998. *Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) – Part 11: Guidance on Usability*. Brussels: CEN.

Jacobsson, M., Goldstein, M., Anneroth, M., Werdenhoff, J., and Chincolle, D. 2000. An action control but no action: Users dismiss single-handed navigation on PDAs. In *Design versus Design. Proceedings of the First Nordic Conference on Computer-Human Interaction (CD-ROM),* eds. J. Gulliksen, A. Lantz, L. Oestreicher, and K.S. Elkundh. 23–25, October 2000. Sweden, Stockholm: Swedish Interdisciplinary Interest Group for Human Computer Interaction (STIMDI).

Jones, M., and Marsden, G. 2006. *Mobile Interaction Design*. Chichester: Wiley.

Jordan, P.W. 1998. *An Introduction to Usability*. London: Taylor & Francis.

Kang, Y.Y., Wang, M.J., and Lin, R. 2004. A study of e-book operation in usability and mental workload. HAAMAHA ’04, Human and Organisational Issues in the Digital Enterprise. In *Proceedings of the 9th International Conference on Human Aspects of Advanced Manufacturing: Agility and Hybrid Automation* Galway, Ireland, August 25–27, eds. E.F. Fallon and W. Karwowski, 489–96. Galway, Ireland: National University of Ireland.

Keinonen, T. 1997. Expected usability and product preference. In *Proceedings of the Conference on Designing Interactive Systems: Processes, Practices, Methods and Techniques*, 197–204. New York: ACM Press.

———. 1998. *One-Dimensional Usability – Influence of Usability on Consumers’ Product Preference*. Helsinki: UIAH publication A21.

Kjeldskov, J., and Stage, J. 2004. New techniques for usability evaluation of mobile systems. *International Journal of Human-Computer Studies* 60 (5–6): 599–620.

Lamble, D., Kauranen, T., Laakso, M., and Summala, H. 1999. Cognitive load and detection thresholds in car following situations: Safety implications for using mobile (cellular) telephones while driving. *Accident Analysis and Prevention* 31:617–23.

Lin, H.X., Choong, Y.-Y., and Salvendy, G. 1997. A proposed index of usability: A method for comparing the relative usability of different software systems. *Behaviour & Information Technology* 16 (4/5): 267–78.

Maguire, M. 2004. What should we require from user interfaces in the future? *The Ergonomist* 414:3.

Nickel, P., Schomann, C., Meyer, I., and Nachreiner, F. 2002. The suitability of the 0.1 Hz component of heart rate variability for usability testing. In *WWDU 2002 – World Wide Work. Proceedings of the 6th International Scientific Conference on Work with Display Units*, eds. H. Luczak, A.E. Cakir, and G. Cakir, 67–469. Berlin: Ergonomic Institut fur Arbeits und Sozialforschung.

Nielsen, J. 1993. *Usability Engineering*. Boston: Academic Press.

Norman, D.A. 1988. *The Psychology of Everyday Things*. New York: Basic Books.

Owen, R.S. 1992. Clarifying the simple assumption of the information load paradigm. *Advances in Consumer Research* 19:770–75.

Owen, R.S., and Haugtvedt, C.P. 1993. Time and consumer information load. *Developments in Marketing Science* 16:55–59.

Pickup, L., Wilson, J.R., Sharples, S., Norris, B., Clarke, T., and Young, M.S. 2005. Fundamental examination of mental workload in the rail industry. *Theoretical Issues in Ergonomics Science* 6 (6): 463–82.

Richardson, M., and Jones, G. 2005. To DIY for: The characteristics that make self-assembly tasks difficult. In *Contemporary Ergonomics*, eds. P.D. Bust and P.T. McCabe, 180–84. London: Taylor & Francis.

Sauer, J., and Rüttinger, B. 2007. Automation and decision support in interactive consumer products. *Ergonomics* 50 (6): 902–19.

Schlegel, R.E. 1993. Driver mental workload. In *Automotive Ergonomics*, eds. B. Peacock and W. Karwowski, 359–82. London: Taylor & Francis.

Segall, N., Doolen, T.L., and Porter, J.D. 2005. A usability comparison of PDA-based quizzes and paper-and-pencil quizzes. *Computers & Education* 45 (4): 417–32.

Stanton, N. 1998. Product design with people in mind. In *Human Factors in Consumer Products*, ed. N. Stanton, 1–17. London: Taylor & Francis.

———. 2001. Ubiquitous computing: Anytime, anyplace, anywhere? *International Journal of Human-Computer Interaction* 13 (2): 107–11.

Stanton, N., and Baber, C. 1998. A systems analysis of consumer products. In *Human Factors in Consumer Products*, ed. N. Stanton, 75–90. London: Taylor & Francis.

Strayer, D.L., Drews, F.A., and Crouch, D.J. 2003. Fatal distraction? A comparison of the cell-phone driver and the drunk driver. In *Proceedings of the 2nd International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, eds. D.V. McGehee, J.D. Lee, M. Rizzo, M. Raby, and L. Boyle, 25–30. Iowa: University of Iowa.

Welford, A.T. 1978. Mental work-load as a function of demand, capacity, strategy and skill. *Ergonomics* 21:151–67.

Wickens, C.D. 2002. Multiple resources and performance prediction. *Theoretical Issues in Ergonomic Science* 3:159–77.

Wickens, C.D., Gempler, K., and Morphew, M.E. 2000. Workload and reliability of predictor displays in aircraft traffic avoidance. *Transportation Human Factors* 2 (2): 99–126.

Wickens, C.D., Lee, J.D., Liu, Y., and Gordon-Becker, S.E. 2004. *An Introduction to Human Factors Engineering,* 2nd ed. Upper Saddle River, NJ: Pearson Education.

Wilson, J.R., and Rajan, J.A. 1995. Human-machine interfaces for systems control. In *Evaluation of Human Work: A Practical Ergonomics Methodology*, eds. J.R. Wilson and E.N. Corlett, 357–405. London: Taylor & Francis.

Young, M.S., and Stanton, N.A. 2002. Malleable attentional resources theory: A new explanation for the effects of mental underload on performance. *Human Factors* 44 (3): 365–75.

———. 2004. Taking the load off: Investigations of how adaptive cruise control affects mental workload. *Ergonomics* 47 (9): 1014–35.

———. 2005. Mental workload. In *Handbook of Human Factors and Ergonomics Methods* (Ch. 39), eds. N.A. Stanton, A. Hedge, K. Brookhuis, E. Salas, and H. W. Hendrick. London: Taylor & Francis.

Young, M.S., Stanton, N.A., and Harris, D. 2007. Driving automation: Learning from aviation about design philosophies. *International Journal of Vehicle Design* 45 (3): 323–38.

7 Intelligence, Creativity, and Decisions in Product Design

Raymy Kate O'Flynn and Thomas Waldmann

CONTENTS

7.1 INTRODUCTION

To a scientist, "designing" may mean devising an experimental method or procedure. To an architect, design can involve structures or material selection. In contrast to scientists, people who think of themselves foremost as designers will concentrate their efforts on producing as many solutions as possible for the design problem, rather than analyze the problem in the way scientists do (Lawson 1979). The difference is a practical one of how to deal with a problem, not one of how the word design is interpreted.

7.2 INSIGHT LEARNING

Cross (1997) describes a "creative leap" as the sudden perception of a completely new perspective on the situation as it had been previously understood. The idea of a creative leap is regarded as central to design. This leap is often seen as necessary to produce an original and novel design proposal. In order to enjoy the moment of a creative leap, it is preferable for the designer to investigate the problem and not to search for immediate solutions. When an "intuitive spark" blesses a team member, he or she will usually work in partnership with others to develop the idea into a viable concept. Subsequent constructive evaluation is required to judge the solutions proposed. Design then takes place in a sequence of stages, when the overall problem is decomposed into subproblems. Designers tend to approach each subproblem separately and finally combine them to form a solution.

Kohler (1927), in interpreting his famous "insight" experiments, did not discount the importance of prior experience for creative problem solving by his chimpanzees. He stated explicitly that if the problems were escalated too rapidly, the chimpanzees would balk. Even in animals, then, we can observe creative behavior, but this behavior is based on prior experience and has to be learned in small steps.

7.3 NOVICE VERSUS EXPERT

What makes a good product designer? Where is the difference between a skilled designer and a novice designer? Designers rely on their memories and experience when solving problems (Marsh 1997). An evaluation following the problem-solving phase allows designers to allocate resources according to knowledge required. Here, the difference between novice and expert designers becomes obvious. With growing experience, designers have an increasingly larger capacity for problem space (Chirstiaans 1992).

7.4 WORKING MEMORY

In a designer's working memory, "bits" of information are stored in "chunks." In experts, each chunk of information tends to contain many more bits of information; novices tend to make up their chunks with fewer bits of information. For example, Kavakli, Suwa, and Gero (1999) found that an expert's productivity and cognitive activity was three times higher than that of a novice:

> The design protocol of the expert was divided into 340 segments containing 2,651 actions while the novice's protocol had 115 segments and 961 actions. Considering that the same amount of time was given to both participants, this indicated that the expert's design protocol was much richer and denser than the novices. It contains almost 3 times as many segments and 2.8 times as many actions as in the novice's protocol. During the design process, the expert produced 13 pages of sketches including 7 different design alternatives, while the novice produced 4 pages including 2 design alternatives. (Kavakli, Suwa, and Gero 1999, 209)

Another difference is that experts tend to re-evaluate and manipulate solutions, while novices produce a higher percentage of drawings and re-evaluate concepts, not solutions, more often (Kavakli and Gero 2001).

7.5 TRIAL AND ERROR

Novice designers adopt a method of trial and error when they search for solutions at the problem-solving stages, which experts do not. Experts are able to use a catalogue of design strategies built up over many years' experience to achieve solutions. In addition, experienced designers develop individual approaches to design tasks, each differing and individually tailored to the specific problem (Ahmed, Wallace, and Blessing 2003). Ho (2001) found that novice designers and experts could be distinguished by the way in which they decomposed a problem. While experts used working-forward strategies, novices worked backwards from the solution. Although a design problem is usually ill structured, Ho (2001) found that good designers can take such a problem and break it into well-defined subproblems.

A designer may have solved the design brief problem, may have used creative tools, made intelligent decisions, and arrived at the desired concept, but the clients will never know if they like the product unless they use it.

7.6 AESTHETIC DESIGN AND PERCEPTION

Aesthetic or visceral design can be the most important part of a design phase and can ultimately "make or break" a product. "Visceral responses involve an automatic evaluation of the perceptual properties of objects, and a quick classification of them as safe or dangerous, good or bad, cold and forbidding or warm and inviting" (Bagnara and Smith 2006, 93). This kind of response is described by Norman (2004) as perceptually induced. This response is so instinctive that users will just know if they like or dislike a product immediately. If designers are emotionally aware enough, they can exploit these immediate perceptions to their advantage. High-level feelings like anxiety or pleasure arise from these immediate perceptions.

7.7 ACTION, REASON, AND AFFECT

After deliberating on the design brief, designers have to act, which corresponds to the way in which people generally make decisions. We can approach decision making either by using analytical tools or by approaching a problem in a naturalistic way. When using our brains to make decisions, we deliberate, we rationalize, and we are analytical. This style of decision making is called reason-based or rational. Reasoning puts serious demands on working memory. Using the heart or making decisions in a naturalistic way suggests we use our emotions and our intuition. This is called affective decision making. This type of decision making is carried out unconsciously, it is automatic, fast, and can run in parallel with other processes. This type of decision making puts little demand on working memory.

7.8 RATIONALITY

"Bounded rationality" was the term put forward by Simon (1955), who criticized established models of decision making for ignoring situational and personal constraints. Many models of human thinking ignored time, personal, and even cognitive capacity constraints. Hence, Simon (1955) suggested that under pressure conditions, the mind would create shortcut strategies that would result in satisfactory solutions. Reflecting on the limitations of human decision making, he stated that we cannot, of course, rule out the possibility that the unconscious is a better decision maker than the conscious. Of the two methods of decision making, the decision process used in everyday life tends to be naturalistic. Naturalistic decision making (NDM) describes how people actually make decisions in real situations, limited by time constraints, uncertainty, with high stakes and vague goals. It employs the use of instincts, hunches, or gut feelings (Gigerenzer 2008). Much of the experimental research into decision making prior to the conception of NDM took place in controlled settings with carefully structured scenarios. Unsurprisingly, it was found that people do not rely on Bayesian statistics or axioms of utility theory, but on heuristics. When confronted with the real world challenges of making quick decisions, people refer to previous knowledge. Similarly, designers are confronted every day with design problems, consultations with engineers, production and manufacturing changes, or rapidly changing markets where consumers regularly change their minds.

7.9 GROUPS

Product designers rarely work in isolation. Whether working in an office, conferring with engineers, or designing with marketers in mind, a designer nearly always collaborates with others.

Designing within the constraints of a group can be difficult and a number of factors need to be taken into consideration. "Group creativity depends on the levels of the individual components in the members of a group and the group's work environment" (Simon 2002). Individual components are the individuals' domain-relevant skills and creativity-relevant processes.

When working in a group, it is necessary to consider each group member's viewpoint and ideas (Lindsley, Brass, and Thomas 1995). Once each member is made to feel like a team member, it is then necessary to provide a well-structured environment with good feedback and task allocation. The combination of coordination of diverse efforts, and careful planning (Brophy 1998) leads to an effective group in which creativity and problem solving necessary in product design is facilitated.

Trying to accommodate various groups and interests during a design project can be a difficult task. In commercial organizations, such a project is usually led by product designers. Hence, their decision-making skills tend to be well developed. Product designers are therefore usually responsible for making decisions that actively shape events, although good designers are not thanked for taking risky gambles.

7.10 HEURISTICS

Heuristics are the elements of NDM, used to rapidly come to a solution that is hoped to be close to the best possible answer, or "optimal solution," and not a risky one (Gigerenzer 2007). The use of heuristics is comparable to the use of educated guesses or rules of thumb. This utilization of intuitive judgment is a quick way of solving a problem at least to a satisfactory level. Heuristics covers the idea of using prior information or recognition of scenarios to solve problems, but it is not without its drawbacks. The use of heuristics can fall victim to cognitive biases or systematic errors. In *Simple Heuristics that Make Us Smart*, Gigerenzer (1999) proposed the idea of using an adaptive toolbox. This collection of methods used where necessary revolutionizes how we make quick decisions. The adaptive toolbox includes several methods, such as "take the best," "ignorance based," and "one reason decision making," for example. Payne, Bettman, and Johnson (1993) suggested a similar approach to decision making, observing the choices made by people depending on their situation. As adaptive decision makers, people had a variety of strategies to choose from. The final choice of strategy depended on circumstance; people looked at the effort needed to implement a strategy and the importance of achieving a high level of accuracy. People then chose the strategy most likely to give a reasonable level of accuracy.

7.11 CHANGE AND ADAPTATION

However, after making a decision, we have to deal with its consequences and further decisions need to be made. As our environment changes over time, we have to employ a method of dynamic decision making (DDM; Brehmer 1992; Edwards 1962). These decisions are more complex than most decisions and include managing factory output, driving a car, or fire fighting. In order to make these types of dynamic decisions, expertise that has been acquired over a period of years is necessary. A well-known test for DDM is the Beer Distribution Game developed by Sterman (1989).

7.11.1 Beer Distribution Game

This game is a simulation of how real people control dynamic and complex decision-making situations. Four players represent the supply chain of manufacturer, distributor, wholesaler, and retailer. Each player begins the game with an inventory of 12 cases of beer, as represented by chips on the board. The game starts with the retailer turning over a card that specifies a level of consumer demand. The retailer then submits an order to the wholesaler, who in turn submits an order to the distributor, who in turn submits an order to the manufacturer (the brewer) (Figure 7.1).

These orders are the only communications that are allowed between players. Once the brewer receives his order, he then ships the beer to the distributor. When the distributor receives the beer, he then ships to the wholesaler, who ships to the retailer, who sells it to the consumers (Figure 7.2).

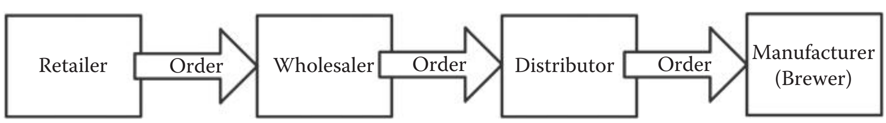


FIGURE 7.1 Chain of events for orders.

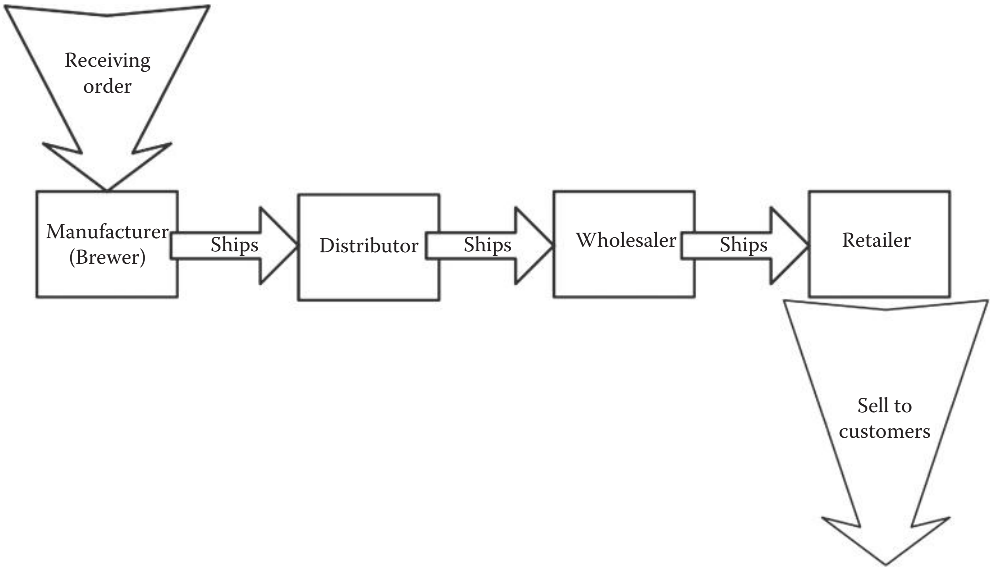


FIGURE 7.2 Chain of events for distribution.

The next round of the game begins after the orders have been shipped. A time delay between placing and receiving an order is a complicating factor in the game. This makes it difficult for the players to know how much beer they should keep in their inventories. For example, while the retailer (or someone else in the chain) is waiting for one consignment of beer to arrive he might receive another order. He does not want to run out of beer, because if he does there is a fine of $1 per case (representing angry customers and lost sales). Therefore, he might wish to keep enough beer in his inventory just in case unexpected orders arrive. On the other hand, he has to incur a charge of $0.05 per case to hold beer in inventory. The initial demand is four cases per week, and remains like this for the first few rounds. Each person in the chain is instructed to order four cases for the first four weeks in order to maintain equilibrium while the players get used to the game. Starting with the fourth week, players can order any non-negative quantity they wish. In the fifth week, customer demand jumps from four cases per week to eight, and stays at this level for the rest of the game. Only the retailer ever gets to see the level of customer demand, but not even he can know in advance what the demand will be.

During the dynamic decision game, players should fall into equilibrium after making some necessary adjustments. This, however, is not the case. With the sudden increase in demand, players tend to over compensate, retailers order 12 cases, wholesalers order even more, and distributors again order more in turn. Because of the delays in the game, players find their inventories running out. Players under pressure place larger orders to compensate for the new flow of demand. Large amounts of inventory build up and once players realize the demand is not so great they respond by cutting back drastically. This cycle of over and under ordering continues as players try to adjust to demand; during this time, players' behavior is said to be driven by an anchoring-and-adjustment heuristic. Instead of making calculations based on ordering patterns and time delays, players tend to anchor their decisions on recent order patterns and inventory levels based on their next order.

7.12 GOOD DECISIONS

An over-emphasis on reasons instead of using fast and frugal heuristics can hinder good decisions (Wilson et al. 1993). Experimental participants were encouraged to choose a poster to take home. One group was asked to give a list of reasons prior to choosing the poster while a second group simply used their intuitive feelings to pick the poster. Six weeks later, the group who was asked to give reasons for their choice of poster was less pleased with their choice than the intuitive group. Despite the influencing factors on decisions, the process itself can be divided into three categories: decision making under conditions of certainty, of risk, and of uncertainty (Luce and Raiffa 1957). As there is always some degree of uncertainty, decisions can be ordered in terms of the level of uncertainty associated with the decision. Most decisions are made under partial uncertainty. One way to make such decisions effective is to base the decisions on similar past experience and use creativity and intelligence to adjust the decisions to the situation where necessary.

The most basic model of decision making, known as maximization of expected value (EV), assumes that decision makers are rational and that they will select a course of action that is at that time the best option. This strategy works by summarizing the value of each option as the sum of values of its potential outcomes, each multiplied by the probability that the outcome would, in fact, be obtained. Once calculated, the option's EV is compared with the EV of other options and the option with the largest EV should be selected, thereby maximizing the EV.

By contrast, the lexicographic method ignores probabilities and does not require a summary of each option, instead it suggests people select an attribute and choose the option that best suits that attribute.

7.13 BRAINSTORMING

Brainstorming is a tool commonly used by designers to generate ideas, procedures, or processes. The tool was popularized by Osborn (1957). It was used to generate huge amounts of ideas and separated the idea generation process from the decision-making process during group sessions. It was found that groups availing of brainstorming sessions did produce more ideas, but at the cost of creativity (Diehl 1987; Stroebe 1987; Mullen, Johnson, and Salas 1991).

There are four main difficulties with brainstorming as a creative tool:

1. Evaluation apprehension (Paulus and Dzindolet 1993): People are concerned with impressing management. Many "blue sky" ideas would be kept to oneself rather than sharing with the group despite instructions to do so. These blue sky concepts would be seen as less than adequate by peers.
2. Social loafing: When working in a group, individuals reduced their effort exponentially as the group size increased. Latane, Williams, and Harkins (1979) demonstrated that during a tug of war the team reduced its effort by 10% as each new member was added to the team.
3. Production matching: People adjusted their view of the normal production rate to match that of their group members, thus reducing their performance levels to suit the group work (Stroebe and Diehl 1994).
4. Production blocking: During a discussion, only one person can express his or her thoughts and ideas at any one time. It was found that during group discussion, participants either disrupted another participant's train of thought or group discussion prevented participants from establishing a productive train of thought (Nijstad 2000).

In an attempt to avoid production blocking, which is seen as the main reason for the ineffective transfer of ideas, Stroebe and Diehl (1994) held that there was a need for greater diversity in groups when brainstorming to allow for a more stimulating environment. They also noted that when brainstorming was supported by electronic means, there was less unnecessary waiting and fewer problems with listening than when using the original brainstorming method.

One way to overcome the problem of domineering brainstormers overwhelming shy participants (whose ideas may well be more original) is by giving each participant access to a computer terminal and the same feedback about ideas on a computer screen. Dennis and Valacic (1993) and Gallupe (1994) report experiments supporting this notion.

Boden (2004) proposed that creativity is the ability to come up with ideas or artifacts that are new, surprising, and valuable. "Ideas" here include concepts, poems, musical compositions, scientific theories, and so on. "Artifacts" include paintings, sculptures, steam engines, and many other things you can name. A successful product designer has to conceptualize, make design or process decisions, and verbalize complex ideas. This tests their creativity, intelligence, and decision making on a daily basis.

"The essence of the idea is that real, genuine creativity is marked by new thinking that has real applications" (Furnham 2008). Creativity can be found in four main states as a creative person, process, situation, or product. In each of these states creativity manifests itself in many ways. Batey and Furnham (2006) collected close to 18 definitions of creativity. Creativity is clearly an important component of how product designers think: Creativity involves the production of novel, useful products (Mumford 2003). As part of a process, creativity was defined by Runco (2004) as a useful and effective response to evolutionary changes. In addition to what may be its most obvious function, namely, as part of the problem-solving process, Eysenck's (1993) definition of creativity included the componential concepts I argue à concepts, "I argue that creative achievement in any sphere depends on many different factors: (a) cognitive abilities—e.g., intelligence-acquired knowledge, technical skills, and special talents (e.g., musical talent, verbal, numerical); (b) environmental variables—such as political-religious, cultural, socioeconomic, and educational factors; and (c) a personality trait—such as internal motivation, confidence, non-conformity, and originality". All or most of these, in greater or lesser degree, are needed to produce a truly creative achievement, and many of these variables are likely to act in a multiplicative (synergistic) rather than additive manner.

7.14 DOES CREATIVITY RELY ON INTELLIGENCE?

In definitions of creativity, the idea that intelligence is necessary to acquire sufficient knowledge to be creative is frequently posited. Barron (1963) proposed the threshold theory, which stated that a moderate level of intelligence was needed to be creative. To recognize that a meaningful problem exists, to select and integrate the relevant information, and to generate an applicable and perhaps original solution, Runco (1991) however, speculated that the correlations between creativity and intelligence scores vary depending on what construct was measured, how it was measured, and under what domain creativity was encouraged and manifested.

This chapter concentrates on the influence of constructs such as creativity and intelligence for the specific purpose of product design. Product design is seen here as a professional activity with, in general, specified objectives, which are not necessarily defined by the designer. Neither artistic endeavor, especially art for art's sake, nor elegant experimental design are addressed. This does not mean that product design has to be commercial, or devoid of fun. An example of fun in product design is reported as part of a paper by Lennon, Bannon, and Ciolfi (2006). They devised the Bin-IT project: The Bin-IT scenario consisted of a set of litter bins that, during quieter periods, traveled from their normal position in the station onto the center of the concourse to move in a choreographed dance. The bins would also move about the station at other times asking people to feed them with their litter, which they did with an enthusiasm never encountered before in Limerick's train station. The Funtheory.com Project (2009) with the objective; "this site is dedicated to the thought that something as simple as fun is the easiest way to change people's behavior for the better. Be it for yourself, for the environment, or for something entirely different, the only thing that matters is that it's change for the better is an impressive example of what can be designed".

7.15 PSYCHOMETRICS

Psychometrics is intended to be a much more general measurement of peoples' abilities than observations used in the discussion of product design processes described so far. Psychometrics relies on operational definitions, such as "intelligence is the score on the intelligence test." Operational definitions are used for measurement, comparison, and prediction. Before attempts at relating intelligence and creativity scores to product design decisions are presented, it is worth speculating on the utility of such scores. A respectable intelligence test has to be reliable, standardized, and valid. The latter is a problem: the IQ score of an intelligence test does not capture what most people, even the majority of psychologists, deem to be an indicator of wisdom, cognitive ability, intellectual acumen, and the ability to benefit from experience. In various ways, Gardner (1999), Sternberg (2001), and Stanovich (2009) all express deep dissatisfaction with the concept of a general intelligence.

A person's IQ scores are hard to change, but rational decision-making skills may not be a reflection of IQ alone and are, therefore, more malleable. IQ tests cannot assess peoples' ability to weigh up information, nor predict how they would cope with their own intuitive cognitive biases. Such skills are, however, beneficial to product designers. IQ tests assess peoples' skills to deliberate, which involves reason and the use of working memory, but they cannot assess how inclined people are to apply them. This distinction shows the extent of peoples' brain power, which IQ tests may measure, versus peoples' control over their brain power, about which IQ tests tell us nothing and which may be improved by training. Although a test resulting in a rationality quotient (RQ) does not yet exist, there is no reason to disbelieve Stanovich (2009) when he expects that a multimillion-dollar research program would eliminate technical and conceptual obstacles for such a test.

7.16 SALIENT KNOWLEDGE AND CRAFTSMANSHIP

Like creativity, performance on an RQ test could probably be improved by training. Leahy and Gaughran (2009) found that catering for preferential learning styles can improve creativity in young students. Thus, there are several aspects of product design in which an apprenticeship or a program of training can be beneficial.

Cooley (1987) and Crawford (2010) point to difficulties with approaching this topic in the way we have here. Although both authors differ in their political outlook, both have warned of the danger of dividing mental labor into segments in the way that physical labor has been divided by Taylorism. If individual people produce only components of the end result, and do not produce complete products, they will be alienated, losing affection for their work. This not only eliminates intrinsic work motivation, but also leads to a loss of skills. This loss of skills could result in there being no-one who could train the next generation to become craftsmen and no-one to repair broken products. Both authors mention examples from architecture, where tasks were decomposed so as to be more amenable to computerization, leading to plans for highly undesirable housing. Decomposing a product designer's work carries with it the danger of taking away the person's craftsmanship.

REFERENCES

Ahmed, S., Wallace, K., and Blessing, L.T. 2003. Understanding the differences between how novice and experienced designers approach design tasks. *Research in Engineering Design* 14 (1): 1–11.

Bagnara, S., and G. Smith. 2006. Theories and practice in interaction design (Chapter 6) *Designers and Users: Two Perspectives on Emotion and Design,* p 93, CRC press.

Barron, F. 1963. Creativity and psychological health. Van Nostrand, Princeton, NY.

Batey, M., and Furnham, A. 2006. Creativity, intelligence, and personality: A critical review of the scattered literature. *Genetic, Social, and General Psychology Monographs* 1324:355–429.

Brehmer, B. 1992. Dynamic decision making: Human control of complex systems. *Acta Psychologica* 813:211–41.

Brophy, D.R. 1998. Understanding, measuring, enhancing collective creative problem-solving efforts. *Creativity Research Journal* 11:199.

Chirstiaans, H. 1992. *Creativity in Design: The Role of Domain Knowledge in Designing*. Utrecht: Lemma.

Cooley, M. 1987. *Architect or Bee?: The Human Price of Technology*. London: The Hogarth Press.

Crawford, M. 2010. *The Case for Working with Your Hands*. London: Penguin.

Cross, N. 1997. Descriptive models of creative design: Application to an example. *Design Studies* 184:427–40.

Dennis, A.R., and Valacich, J.S. 1993. Computer brainstorms: More heads are better than one. *Journal of Applied Psychology* 784:531–37.
Diehl, M., and Stroebe, W. 1987. Productivity loss in brainstorming groups: Toward the solution of a riddle. *Journal of Personality and Social Psychology* 533:497–509.
Edwards, W., Lindman, H., and Savage, L.J. 1963. Bayesian statistical inference for psychological research. *Psychological Review* 703:193–242.
Furnham, A. 2008. *Personality and Intelligence at Work*. London: Routledge.
Gardner, H. 1999. The theory of multiple intentelligences: A personal perspective. In *Intelligence Reframed: Multiple Intelligences for the 21st Century,* p. 35. New York, NY: Basic Books.
Gigerenzer, G. 1999. *Simple Heuristics That Make Us Smart*. New York: Oxford University Press.
Gigerenzer, G., Hoffrage, U., and Goldstein, D.G. 2008. Fast and frugal heuristics. *Psychological Review* 1151:238–39.
Ho, C.-H. 2001. Some phenomena of problem decomposition strategy for design thinking: Differences between novices and experts. *Design Studies* 221:27–45.
Kavakli, M., and Gero, J.S. 2001. Strategic knowledge differences between an expert and a novice. In *Strategic Knowledge and Concept Formation III. Key Centre of Design Computing and Cognition*, eds. J.S. Gero and K. Hori, 55–68. Australia: University of Sydney.
Kavakli, M., Suwa, M., and Gero, J.S. 1999. Sketching interpretation in novice and expert designers. In *Visual and Spatial Reasoning in Design: Key Centre of Design Computing and Cognition*, ed. J.S. Gero and B. Tversky, 209–20. Australia: University of Sydney.
Kohler, W. 1927. *The Mentality of Apes.* New York: Harcourt Brace.
Latane, B., Williams, K., and Harkins, S. 1979. Many hands make light work: The causes and consequences of social loafing. *Journal of Personality and Social Psychology* 376:822–32.
Lawson, B.R. 1979. Cognitive strategies in architectural design. *Ergonomics* 22:59–68.
Leahy, K., and W. Gaughran. 2009. Preferential learning styles as an influencing factor in design pedagogy. *Design and Technology Education: An International Journal* (Awaiting Publication).
Lennon, M., L. Bannon, and L. Ciolfi. 2006. Space to reflect: Combinatory methods for developing student interaction design projects in public spaces. *CoDesign* 2:53–69.
Lindsley, D.H., Brass, D.J., and Thomas, J.P. 1995. Efficacy-performance spirals: A multilevel perspective. *The Academy of Management Review* 203:645–78.
Luce, R.D., and Raiffa, H. 1957. *Games and Decisions: Introduction and Critical Survey*. New York: Wiley.
Marsh, J.R. 1997. The capture and utilisation of experience in engineering design. PhD thesis, Cambridge University, UK.
Mullen, B., Johnson, C., and Salas, E. 1991. Productivity loss in brainstorming groups: A meta-analytic integration*. Basic & Applied Social Psychology* 12:3–23.
Nijstad, B.A. 2000. How the group affects the mind. Unpublished.
Norman, D.A. 2004. *Emotional Design*. New York: Basic Books.
Osborn, A. F. 1957. Applied imagination (revised edition). New York: Scribner's.
Paulus, P.B., and Dzindolet, M.T. 1993. Social influence processes in group brainstorming. *Journal of Personality and Social Psychology* 644:575–86.
Payne, J.W., Bettman, J.R., and Johnson, E.J. 1993. *The Adaptive Decision Maker*. Cambridge: Cambridge University Press.
Runco, M.A., S.M. Okuda, and D.E. Berger. 1991. Creativity and the finding and solving of real-world problems. *Journal of Psychoeducational Assessment* 9:45.
Simon, H.A. 1955. A behavioral model of rational choice. *The Quarterly Journal of Economics* 691:99–118.
Simon, T. 2002. Individual creativity and group ability to utilize individual creative resources: A multilevel model. *The Academy of Management Journal* 452:315–30.
Stanovich, K. (2009). What intelligence tests miss: The psychology of rational thought. Yale Univ Pr.
Sterman, J.D. 1989. Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. *Management Science* 353:321–39.
Sternberg, R.J. 2001. What is the common thread of creativity? Its dialectical relation to intelligence and wisdom. *The American Psychologist* 564:360–62.
Stroebe, W., and Diehl, M. 1994. Why groups are less effective than their members: On productivity losses in idea-generating groups. *European Review of Social Psychology* 5:271–303.
Wilson, T.D., Lisle, D.J., Scholer, J., Hodges, S.D., Klaaren, K.J., and La Fleur, S.J. 1993. Introspecting about reasons can reduce post-choice satisfaction. *Journal of Personality and Social Psychology* 193:331–39.

8 Role of Standards in Design

Magdalen Galley-Taylor, Anne Ferguson, and Gordon Hayward

CONTENTS

8.1 INTRODUCTION

Standards are not blueprints for products (at least as far as consumer products are concerned), so they do not replace the need for experienced designer(s) with the technical education, experience, and creativity to specify functional capabilities, materials, form, size, tolerances, appearance, and user interfaces. They may impose constraints on designers, but only as much as is necessary for the good of consumers—typically to ensure appropriate performance in relation to factors such as safety, usability, and inclusivity.

Standards can be valuable tools for designers as the combined knowledge that they encapsulate is broader based than the lifetime experience of any individual designer, market-leading company, or even one whole industry, since knowledge of how to achieve best practice is often transferable between product sectors. The role of standards is to save individual designers from recreating aspects of designs that have been found to result in product failure in the past. The sorts of "failures" consumers want avoided are not limited to products breaking or ceasing to work, but extend to issues such as safety, fitness for purpose (usability), efficiency, accessibility, quality of life, and environmental protection. Standards are attempts to collect in one place practicable rules or methodologies for ensuring that products incorporate those lessons—through specification in design and testing of finished samples—in preference to each designer or company having to re-learn the same lessons for themselves through consumer complaints, legal actions, and poor sales.

Although beneficial to industry and consumers alike through application of established good practice, standards are sometimes perceived by designers as being too rigid, unreasonably design restrictive and stifling innovation and creative thought processes. However, rather than limiting creativity, having to meet several apparently conflicting restrictions can stimulate creative designers to come up with more radical solutions—whether these concern overall product concepts or just detail features.

The form standards take is a consequence of the input of the committee developing the requirements and their response to comments interjected during the consultation phases. Designers and ergonomists are legitimate stakeholders in the standards development process; their presence around the table can help to ensure that criteria imposed are only as much as is necessary to achieve the relevant objective and continue to provide opportunities for design innovation.

Standards can be thought of as informal or formal. Informal standards can be as straightforward as having company guidelines on how a product is made or how a service is carried out. Formal standards are likely to be codified by industry and trade associations or consensually agreed in national or international committees. Formal standards, developed under the auspices of a national or international standards body, set out criteria agreed by industry and other relevant stakeholders. They draw together best practice from industry experts, government, testing and certification organizations, academics, consumer groups, trade associations, and business. Formal standards can cover both the products (or services) themselves and specific parts of how they are created and delivered.

Formal standards are a way in which designers, manufacturers, trainers, and evaluators can ensure a level of safety, quality, and performance across products, organizations, disciplines and, in some cases, nationalities. They provide a blueprint for industry and represent organizational wants, needs, and expectations (Priest, Wilson, and Salas 2006).

The formal standards that most people think of, and designers are accustomed to take into account, are performance or construction standards, specifying a product's materials or capabilities. With the development of more "generic" or "horizontal" standards that consider user needs and facilitate the design process, designers can make use of standards that help to ensure that quality is present throughout design management, production, and communication with the consumer. Following procedural standards does not provide a designer with a short cut to omniscience; the finished products themselves still need to take account of all the knowledge of past failures accumulated in traditional standards, and gathering this information cannot be avoided. Unfortunately, as recognized by Salvendy and China (2006), "When designing products, services and workstations…, the various ergonomics guidelines and standards are scattered in a large number of diverse documents around the world; hence the practitioner has great difficulty accessing them."

8.2 ROLE OF FORMAL STANDARDS

8.2.1 Introduction

Formal standardization is the means by which society gathers and disseminates technical information (Spivak and Bremmer 2001). Standards provide quality control, support legislation and regulation, and ensure equal opportunity and fairness in international markets. They also ensure uniformity and interchangeability, reduce barriers to trade, promote safety, allow interoperability of products, systems and services, and promote technical understanding (Wettig 2002).

Every day, consumers benefit from standards in many ways. Sometimes manufacturers and designers draw attention to standards on products as a sign of quality, but generally their influence on price, comfort, performance, and safety goes unnoticed even though standards and regulations directly affect over 80% of world products trade worth over €3 billion (CEN leaflet 2006).

Consumers would soon notice if there were no standards as they make an enormous contribution to our lives. For example, we quickly become aware when equipment turns out to be of poor quality, is incompatible with equipment we already have, is unreliable or dangerous. When products meet expectations, consumers tend to take this for granted and are unaware of the role that standards have played in their satisfaction and in the broader contribution to the economy (ISO 2007). According to ANEC* (2003), for consumers, standards may contribute to

- Accessibility and design for all
- Adaptability
- Consistency of user interfaces
- Ease of use
- Functionality of solutions
- Service quality and response time
- System reliability and durability
- Health and safety
- Environmental issues
- Information (pre-purchase, on or with the product and customer support)
- Privacy and security of information
- Interoperability and compatibility (e.g., batteries)
- Multi-cultural and multi-lingual aspects
- Market transparency (e.g., bedding Tog ratings)
- Lower prices

A lack of standardization may affect the quality of life of some people, such as disabled people who may be prevented from accessing consumer products and services, public transport, and buildings because their specific user need has not been appropriately taken into account, e.g., entrances that do not take into account the dimensions of wheelchairs.

8.2.2 Standards Bodies

Formal standardization takes place at an international, regional, and national level. There are three organizations operating in partnership at international level: the International Organization for Standardization (ISO), the International Electrotechnical Committee (IEC), and the International Telecommunications Union (ITU).

At a regional level within the European region there are three complementary standards bodies: the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunications Institute (ETSI). In the Southern hemisphere, the Australian and New Zealand standards bodies sometimes operate jointly as a regional body that issues joint standards.

Most nations have a single national body, such as the British Standards Institution (BSI), Standards Australia, Standards New Zealand, South African Bureau of Standards, and so on. By contrast, the United States, for example, has the American National Standards Institute, as the national standards body, which draws from a large number of independent bodies that develop and publish consumer product standards. Some of these are general, such as the American Society for Testing and Materials

* ANEC is the European consumer voice in standardization, representing and defending consumer interests in the process of standardization and certification, also in policy and legislation related to standardization.

(ASTM) and Underwriters Laboratories, some sectoral such as IEEE-USA (standards for electronics) and some specialist, such as the Snell Memorial Foundation (standards for sports helmets).

These various bodies produce a range of different designations of documents including standards, guidelines, codes of practice, published documents, technical reports, and so on, each of which has a different status, although few, if any will be mandatory.

8.2.3 Standards and Legislation

Standards are conventionally described as voluntary requirements produced by consensus, whereas regulations are mandatory requirements produced by government. The situation is not always clear-cut, in some cases standards and regulations come together.

A few ISO standards, mainly those concerned with health, safety, or the environment, have been adopted in some countries as part of their regulatory framework or are referred to in legislation for which they serve as a technical base. Conversely, ECE Reg 44 (1998 plus amendments to 2005), is in practice the European standard for child restraints in vehicles, which (for historical reasons) is produced by the United Nations Economic Commission for Europe. Within its responsibility for transport, this international agency produces a number of "regulations." Similarly in the UK, "The Wiring Regulations" are not legislation but a voluntary British Standard, and what many professionals refer to as "The Building Regulations" are in fact non-mandatory UK government guidance documents that make more detailed requirements than the statutory regulations bearing the same name.

Legislation such as European directives and U.S. laws may specify particular standards in quantitative requirements and tests or may take a more generic approach. The New Approach Directives from the European Union (EU) define what is termed the essential requirements (ERs) covering health, safety, and the environment in a number of areas. Typically, they require designers and manufacturers to identify all hazards to health and safety, then carry out a risk assessment and, on the basis of the risk assessment, eliminate or minimize the risks by (in order of precedence):

- Design measures
- Provision of protective devices
- Provision of information on residual risks and the precautions needed to deal with them

Conformity with particular standards is not generally mandatory and where a directive exists, a designer or manufacturer may choose any technical solution that fulfils the ERs of the directive and keep a record of how they have done this. However, some inherently dangerous products must be type-tested and certified by approved independent test laboratories, e.g., gas appliances in the EU.

Where products (or individual hazards) fall outside the scope of specific "sector" directives, they are covered by the EU's General Product Safety Directive (2001). No prior certification is required under this law. However, in the event of any legal challenge, the determination of compliance requires a product to be assessed by taking into account available official standards, codes of good practice, the state of the art at the time of manufacture, and consumer expectations of safety.

Several directives advise that the best source of information for designers attempting to address the ERs are those "harmonized standards" produced by national and regional standards bodies such as CEN/CENELEC and the international standards bodies ISO/IEC, and then officially listed by the European Commission. Conformity with these standards can sometimes bestow a presumption of compliance with the ERs of the directive.

Similarly, when defending product liability claims (including those arising in the United States), designers or manufacturers may introduce evidence that they complied with voluntary industry standards and customs to rebut a negligence or defective design claim and to show that they exercised reasonable care in the design, manufacture, or marketing of their product. However, compliance with industry standards and customs does not automatically absolve the defendant from liability. In the United States, a jury weighs that evidence (together with other evidence presented) in deciding whether the care exercised by the defendant was sufficient, under the circumstances; while in the EU, judges do not have to decide whether the manufacturer was negligent, only that a product did not provide the safety that a consumer was entitled to expect and that it was responsible for an injury.

8.3 DESIGNING TO FORMAL STANDARDS

8.3.1 Introduction

Standards are only as good as the input from the technical committee or working group that develops them and the extent to which wider comments during the consultation phase shape the final document. Designers and ergonomists should thus aim to be involved in the development process of relevant standards whether directly on technical and project committees or by feeding in comments at the various consultation stages during standards development (which include seeking comment on the "new work item" proposals, at least once during the drafting phase of the standard).

Standards are not blueprints for products (at least as far as consumer products are concerned), so they do not replace the need for experienced designer(s) with the technical education, experience, and creativity to specify functional capabilities, materials, form, size, tolerances, appearance, and user interfaces.

In their book, *Designing Safety into Products*, Norris and Wilson (1997) identify two separate aspects of product safety: construction safety and design safety. Construction safety covers such things as materials, components, and manufacturing quality, while design safety extends to whether the concept and presentation of the product provides users, including non-intended users, with the level of safety they might reasonably expect. Norris and Wilson identify standards as one of the ways in which product safety can be achieved, but go on to acknowledge that this may be only a basic level of safety and that a higher level of safety, and indeed really good usability, can often be achieved only by a thorough and systematic product evaluation.

In addressing the question of how to address risk, Hood and Jones (1996) state that the traditional approach has essentially been to design product standards that will ensure that they are safe with a specified set of functions or at least "safe enough" within cost-benefit constraints. Such standards often rely heavily on negotiated notions of feasibility, practicality, and reasonableness on which it is often difficult to obtain agreement within a standards committee. This led to some product standards (notably for many years almost all domestic electrical products) not addressing the additional risks involved in their use by certain groups, e.g., children, elderly or disabled people—even for products that it was clear were regularly used by these "non-standard" consumers. However, work is underway at international, regional, and national levels to rectify these past flaws (see Section 8.4).

8.3.2 Not Everything is Covered by Standards

Designers need to be aware that practices vary from sector to sector as to whether all safety requirements for a particular product will be found together in one standard (taking into account other standards to which it refers). For example, in the child care sector there are separate standards for baby walkers, playpens, carry cots, etc., each of which aims to present a comprehensive set of safety requirements for that type of product. IEC standards for each type of domestic electrical product are similarly comprehensive except for leaving the manufacturer to choose the mains supply voltage and design of plug (because these issues are usually subject to national regulations).

In sharp contrast, within the furniture sector, standards have usually addressed each physical property (strength, stability, ergonomics, flammability, use of glass, etc.) in a completely separate standard with several levels of performance. Consequently, there was no easily identified comprehensive safety standard to which a product, e.g., a domestic chair, table, or storage unit, could be designed or certified. CEN standards for furniture are slowly improving this situation by developing a separate part for each property within a standard for each type of product.

Work is underway in Project Committee ISO PC 243 to look at generic issues of product safety that will be of use where there are no specific safety standards covering a particular product. It is proposed that there will be a wide and flexible scope and that the ensuing standard will provide universally applicable guidance and practical tools to identify, assess, and eliminate or reduce potential safety risks, so that they can be addressed before the products enter the market. The guidance will be directed to all parties involved in the consumer product supply chain (designers, manufacturers, importers, distributors, retailers, etc.).

Standards are often in the process of revision to catch up with the inventiveness of designers in adding functions and features to products or combining two product concepts. This is common in the child-care area where multi-functional products are developed, e.g., a back-pack child carrier that also doubles as a stroller, or novel designs such as three-wheeled strollers where the stability test developed for four-wheelers is not appropriate. Sometimes standards writers sufficiently anticipate developments to exclude them from the scope of a standard (e.g., the CEN standard for skateboards specifically excludes motorized versions), but often this is not possible (e.g., the CEN standard for bouncing baby chairs did not specifically exclude models that can be converted into fully reclined rocking cradles or fitted with carrying handles and folding sunshades, but neither did it include safety requirements covering these additional features). In general, the process of standardization has been speeded up over recent years and there are mechanisms for addressing such issues within a reasonable time frame.

8.3.3 Availability of Test Methods

The comprehensiveness of standards is generally limited to those potential hazards or failings for which a satisfactory test method has been developed. For example, the first standards for child safety barriers included no requirements to address the most onerous situation that they face, namely, children rattling them loose when unsupervised, as there was no acceptable test method. If the barriers failed under this assault then the consequences were the risk of children falling down stairs and steps. Once a repeatable and reliable test was developed, this was added to the standard, ensuring better performing products.

8.3.4 Failure to Consider the User Population

The evidence on the usability (or rather lack of it) of a whole range of products by older users is overwhelming, suggesting that standards either failed to cover usability issues or failed to take account of the needs of many real users or, indeed, that designers have failed to take into account relevant standards which do address such needs. Whatever the reason, this means that many older users have difficulty operating the entire array of consumer products because the five components of usability: learnability, efficiency, memorability, error tolerance, and satisfaction have not been addressed (Fisk et al. 2004).

Designers seeking to take account of older or disabled users need to look beyond product-specific standards and seek guidance and descriptions of good practice that may be published by standards bodies but not as standards against which products are expected to be certified or tested. Rather, they need to look at specific guidance and technical reports, some of which are aimed at the standards developer but have value to others involved in the product design process, such as ISO/IEC Guide 71, described later.

8.4 STANDARDS COVERING SPECIFIC POPULATIONS

8.4.1 Introduction

Typically, in the past, most national and regional standards considered the needs of children, older people, or people with impairments only if the subject of the standard was a product specifically aimed at them, e.g., child care products, walking aids, or assistive technology. The needs of these groups were not adequately addressed when standards for general purpose products and services were written or revised. However, standards bodies are now much more effective in addressing aging and disability issues and hopefully suppliers will, increasingly, develop and implement policies and programs in their products and services to include the needs of such user groups. It is important to ensure representation of the interests of older people and people with disabilities in the development of these solutions (ISO/IEC Guide 71 2001). An additional motivating factor for designers and manufacturers is the increased amount of disability legislation throughout the world that addresses access to buildings, goods, and services. This alternative approach of developing horizontal guidelines that address a population group has also been extended to some common features such as instructions or packaging. Thus, a number of ISO guides have now been developed that do consider these special groups and information on them is presented below.

Some standards that clearly put users, their characteristics, and probable behavior as the focus, include the suite of ergonomics and human factors standards, considered in Section 8.5, and the ISO/IEC guidelines on including safety in standards (Guide 51 1999). At the time of writing, revision of this document had just started.

Guide 51 describes a risk management approach to reducing safety hazards arising from the use of products, processes, or services. Although aimed at the standards developer, when drawing up the detail of a standard, the guidance is equally relevant to the designer. The approach described includes identifying likely user and contact groups, considering both intended use *and* reasonably foreseeable misuse, identifying each hazard *at every stage of use* (including eventual disposal), estimating and evaluating risk to all users and people who may come into contact with the product or service (someone just standing by), and reducing the risk of damage or injury if the level of risk is not tolerable.

8.4.2 Children

ISO/IEC Guide 50 (2002), which provides guidelines for child safety, builds on the risk management approach described in Guide 51 (see Section 8.4.1), clearly recognizing that child safety should be a major concern for society because accidental injuries are a major cause of death and disability to children and adolescents in many countries. It is likely that revision to this document will take place as work on the related Guide 51 proceeds. Guide 50 calls on designers and manufacturers, as well as standards developers, to acknowledge that children do not misuse products but rather interact with them in ways that reflect normal child behavior, which will vary according to the child's age and level of development. The challenge is to develop products, structures, installations, and services (collectively referred to as *products*) in a way in which the potential for injury to children may be minimized.

This guide provides a general approach to child safety, including the principles for a systematic way to address hazards and details of developmental characteristics of children that place them at particular risk of injury. Specific hazards to which children might be exposed during their interaction with a product, such as mechanical, thermal, and chemical hazards, are also identified, along with specific suggestions for addressing them.

A European document on the inclusion of child safety in standards, CEN/CENELEC Guide 14 (2009), complements ISO/IEC Guide 50 and ISO/IEC Guide 51. Guide 14 builds on the ISO/IEC guides, offering mechanisms to enable the user of the guide to reach appropriate solutions in a structured way. Again aimed at standards developers, as an *aide-memoire* to assist them in taking children's safety into account when writing standards, it can be used by designers to help consider the needs of children when designing everyday consumer products. Of particular value are the examples of what children can do at different stages of development, the resulting hazardous behaviors and characteristics and potentially effective preventive measures.

For any designers involved in child care products, especially multi-functional or novel ones, the generic CEN document, CEN TR 13387 (2004): *Child use and care articles—General and* *common safety guidelines*, provides an excellent summary of the hazards that are common to all such products (including chemical, mechanical, and thermal) as well as providing advice on appropriate product information to supply to consumers.

8.4.3 Elderly or Disabled People

The international ISO/IEC Guide 71 (2001) (adopted in Europe as CEN/CENELEC Guide 6 2002) provides guidance for standards developers on addressing the needs of older people and those with disabilities when writing standards, building on the principles set out in an ISO/IEC Policy Statement (2000). As its Introduction states, Guide 71 is also potentially of help to designers. The guide includes tables and text to help identify factors such as "lighting/glare" or "surface finish," which will affect the use of a product, service, or environment and to consider their significance for persons with different abilities, with some limited information on what action can be taken. Abilities include sensory, physical, and cognitive abilities, together with guidance related to allergies, recognizing that while not typically recognized as a "disability," allergies can impose limitations on an individual's activities and, in some cases, be life threatening. Some information is given on the effects of aging and the practical implications of impairment. For example, under "seeing," the section on "effects of aging" lists changes such as "loss of visual acuity," "reduced field of vision," and "sensitivity to light." Under "risk of hazards," "sharp points" and "hot surfaces" appear. The final section of Guide 71 is a bibliography, which offers a list of sources that can be used to investigate more detailed and specific guidance materials with respect to accessible design. The guidance provided in Guide 71 is general; usability issues for people with impairments are identified without specific solutions.

ISO/TR 22411: 2008 is a recently published technical report that provides the principles and techniques of accessible design for products, services, and environments, and related ergonomic data on human abilities (vision, hearing, strength, cognitive ability, and allergy), along with basic anthropometric data to supplement the general information given in ISO Guide 71. This document is aimed particularly at the needs of standards developers who require such information to provide the basis for establishing criteria for accessibility. However, the same data is of potential value to designers. Inevitably, some of the information is complex and will require good understanding on the part of the designer, or the assistance of those knowledgeable in ergonomics and human factors, to be correctly interpreted into design solutions. However, work is already underway to make the document more accessible to designers and to add additional information about human abilities that are relevant to achieving accessibility for older people and people with disabilities.

An example of the application of such guidance is provided by the work of IEC TC 59 WG 11,* which is writing guidelines for IEC TC59 subcommittees on how to apply the information in IEC/ISO TR 22411 to their standards. The initial priorities for this work are the more frequently used kitchen appliances, such as toasters and washing machines.

8.5 ERGONOMICS AND HUMAN FACTORS STANDARDS

8.5.1 Introduction

As a discipline, ergonomics is in the unusual position of being singled out within CEN and ISO for its own specific committees, which are responsible for standards that affect a whole range of products. In the last 30 years there have been more than 150 ergonomics standards published by ISO and CEN and this has, inevitably, led to some duplication and contradictions (ISO 2007).

* The technical committee looking at the accessibility and usability of household electrical appliances.

8.5.2 International Ergonomics Standards

The "mother" ISO standard for ergonomics was originally developed within the International Standards Committee (ISO TC 159) in 1981 as ISO 6385: *Ergonomics principles in the design of work systems*, and revised in 2004. The content of ISO 6385 is now being revised and extended to cover the full range of modern ergonomics applications, including basic terms and concepts and their application to the design and evaluation of tasks, jobs, products, services, environments, and work systems, in order to make them compatible with the needs, abilities, and limitations of people. To take account of this widened scope, the new document will be published as ISO 26800: *Ergonomics—General approach, principles and concepts*. Designers are listed among the intended users.

The various subcommittees of ISO TC 159 consider particular aspects of ergonomics: anthropometry and biomechanics; ergonomics of human system interaction, such as the placement of controls and visual display requirements, and the physical environment (auditory, visual, and thermal). They are thus involved in the development of a wide range of standards. A suite of standards, which has a wider application than the name would suggest and may have some relevance to designers of consumer products, is the ISO 9241 series (various dates from 1992 to 2006). Parts 1–17 on "Ergonomic requirements for office work with visual display terminals (VDTs)" each cover very specific aspects, such as requirements of the keyboard, other input devices and displays, and the presentation of information. Parts are, in some cases, now very old but, together with a title change (Ergonomics of Human System Interaction), there is a program of updating being carried out to include the needs of older people and those with disabilities.

At the time of writing, *Human centered design processes for interactive systems*, ISO 13407 (1999), which provided guidance on following a human-centered design process, with emphasis on active involvement of users, including evaluating designs against requirements in user trials, was being revised and incorporated in the ISO 9241 series with probable publication as ISO 9241:210 in 2010.

There is a four-part standard ISO 20282 on ease of operation of everyday products. Part 1 (ISO 20282-1:2006) gives design requirements for context of use and user characteristics; Part 2 (ISO/TS 20282-2:2006) provides a test method for walk up and use products; Part 3 (ISO/PAS 20282-3:2007) is a test method for consumer products; and Part 4 (ISO/PAS 20282-4:2007) is a test method for installation. The everyday products that have been considered are characterized by having interactive controls and being likely to be used by untrained consumers or the general public in circumstances where they are unlikely to read extensive instructions (e.g., alarm clocks in hotels, electric kettles, telephones). Walk up and use products are those that provide a service to the general public (e.g., ticket vending machines, photocopying machines, fitness equipment). Other categories of products are those used in a work environment, but not as part of professional activities (e.g., a coffee machine in an office) and products including software or communications technology to support the physical functions of the product (e.g., a CD player or an in-car GPS system). The standard considers the sources and range of variation in user characteristics, and in particular focuses on the needs of older people.

The majority of the remaining international ergonomics standards do not relate to consumers but there may be aspects that will be of interest and a full list of current standards can be found on both the ISO and the International Ergonomics Association's (IEA) websites.

Other ergonomics issues that are often left out of consumer product standards are covered in guidance documents or generic standards. These issues include product packaging and the information provided to consumers.

8.5.3 Packaging

ISO/IEC Guide 41 (2003): *Packaging—Recommendations for addressing consumer needs*, aims to address the safety, comfort, and reliability of consumer packaging as well as the intended health protection function and such general needs as protection of the environment and energy conservation. Its target audience includes product designers. The standard is concerned with consumer packaging rather than bulk and transport packaging. It seeks to eliminate unnecessary packaging but ensure that goods reach consumers in the condition intended by the manufacturer and provide an appropriate means of storage, while protecting consumers from any potentially harmful effects of the packaging or its contents, and enabling them to be disposed of, or recycled, in a manner that minimizes their environmental impact. What the current Guide 41 does not do is address the real usability issues of packaging, especially for those with impaired hand function. For this, designers will need to cross reference to Guide 71 aimed at older and disabled people. This aspect is now (2010) being addressed by CEN within the packaging committee under the title "Packaging – Ease of opening – Criteria" and a test method for evaluating consumer packaging. This is likely to be published as a technical specification because the test methodology is still under development. However, its stated target audience does include designers and manufacturers. The ISO packaging committee is also working on a standard for accessible packaging, based on the principles of Guide 71. The present standard under development does not state the dimensions, materials, manufacturing methods, or evaluation methods of individual packages, but is in the form of general guidelines. However, it is understood that other aspects are to be specified in separate individual standards in the future.

8.5.4 Information

Information for consumers is a vital part of any product, both before and after purchase, and "instructions" are the means of conveying information to the user on how to use the products and product-related services in a correct and safe manner. As means of communication, texts, words, signs, symbols, diagrams, illustrations, and audible or visible information are used, separately or in combination. They may be on the product itself or its packaging or in accompanying materials, e.g., leaflets, manuals, audio and video tapes, CDs, and computerized information such as the provider's web. If reliance is placed on just one medium, one phrase, or one graphic to communicate a vital safety message, then some proportion of consumers will not receive it and another proportion will fail to recall and act on it at the crucial moment. Many research studies into the effectiveness of product instructions and warning labels have continued to find a wide variation in the probability of individual consumers noticing, reading, and complying with product instructions.

The effectiveness of instructions in preventing harm can never be assumed to be as good as supervised training or designing the product to be fail-safe (when this is possible). The aim of such guidance is to maximize the amount of necessary knowledge conveyed, understood, and remembered by each user of the consumer product. There is an international standard for writing instructions (IEC 62079 2001), but a more succinct introduction is provided by ISO/IEC Guide 37 (1995). Intended for product designers among others, it offers general principles and detailed recommendations on the design and formulation of all types of instructions and warnings necessary or helpful to the final user of consumer products. Guide 37 confirms the principle enshrined in product liability law that instructions are part of the product. (A new version of the guide will be published in 2011, soon after which the revised standard should appear, re-designated as IEC/ISO 82079).

ISO IEC Guide 14: 2003: *Purchase information on goods and services intended for consumers*, aims to improve the quality of pre-purchase information, thereby increasing consumers' ability to make a reasoned choice at the point of purchase. It helps to minimize the risk of incorrect or inappropriate purchases or contracts. Those who supply a high standard of consumer information enhance their commercial reputation, and save time and money by reducing enquiries and complaints. The guide outlines general principles and recommendations for contents, methods, formats, and design, such that the information will enable consumers to compare and choose products or services.

CEN/CENELEC Guide 11 (2006): *Product information relevant to consumers*, summarizes the whole process of delivering information about products to consumers from purchase choice through to operation, after sales communications, and disposal, giving guidance for both standards developers and product designers and producers.

ISO/IEC Guide 74 (2004) gives technical guidelines for the consideration of consumers' needs when designing or choosing graphical symbols for use on products. Without doubt, graphical symbols can have important benefits in the field of communication, as they have visual impact and can provide information in a compact form that is independent of language. They can also be used to guide the viewer to a desired outcome or appropriate decision. However, these benefits are not always achieved in practice. Poorly designed and researched graphical symbols can cause confusion for consumers, as can the proliferation of graphical symbols with the same intended meaning. Such problems will become more common in an age of mass travel, mobility of labor, and global trading, unless graphical symbols are designed, evaluated, and standardized in accordance with procedures set out in the relevant international standards. ISO 7000 (2004) catalogues already standardized symbols while the purpose of ISO IEC Guide 74 is to ensure that the needs of consumers are adequately addressed when a possible new requirement for a graphical symbol is being considered.

8.6 USING STANDARDS IN THE DESIGN PROCESS

8.6.1 Design Management

In the UK there are some useful standards in the BS 7000 series "Design management systems," although there is no international version of these. Of particular interest is BS 7000-6 (2005): *Managing inclusive design*, which indicates that having an inclusive philosophy to design management will benefit the organization in a number of ways, including improved quality of products, increased sales, and customer satisfaction and loyalty. The standard describes a process for adopting a professional approach to inclusive design at the organizational level, together with the necessary steps to take to manage inclusive design at the project level. There are several checklists to use at different stages of the design process and the Annex includes relevant tools and techniques to adopt, e.g., to use data to design inclusively and to evaluate products. This standard is currently being considered for revision and in the UK, for example, work is starting on topical areas such as "Sustainable Design."

8.6.2 Finding Applicable Standards

It can be difficult to identify all the applicable standards for some products—particularly for different countries. Also, there are "cutting edge" products yet to have a standard but designers must still make safe, useable products. Adopting requirements from standards for other products, where relevant, can help in this process.

There are several databases of standards, such as the site of the commercial bookseller, IHS Standards Store, which includes most national standards bodies and many trade associations. The Standards Database Perinorm provides details of standards from 23 countries. The ISO's entire portfolio of standards is listed on the ISO Catalogue, which can be accessed online. The site also provides access to the World Standards Services Network (WSSN), which is a network of publicly accessible web servers of standards organizations around the world. Other useful websites to search for standards include the ITU, the Worldwide Web Consortium (W3), the EU's Europa Website, the CEN, the CENELEC, and the ETSI. The IEA website also lists the international ergonomics and human factors standards. Information on these organizations is given in Section 8.7.

Various national organizations have their own searchable databases, for example, in the UK, standards can be searched for online using British Standards Online (BSOL)—BSI's bibliographic, citation, and full-text database of more than 50,000 British and adopted European and international standards.

8.6.3 Products that have no Specific Standard

Taking Europe as an example, products that are sold under the jurisdiction of EU sectoral safety directives, and that cannot meet any existing standard, will usually need a certificate of compliance with the essential safety requirements to be issued by an authorized testing body, prior to being placed on sale. These bodies usually base their certification on subjecting a sample product to tests they consider relevant, compiled from standards (or draft standards) for similar products (or products with similar hazards), combined with their own experience of product hazard analysis.

No such prior certification is required for products sold in the EU, which are subject only to general product safety regulations. In the EU and elsewhere, however, designers would be well advised to seek the advice of experienced test laboratories or follow their approach of conducting a hazard analysis and compiling a set of tests or requirements to check that each hazard is addressed by protective measures from existing standards.

The previously mentioned ISO/IEC Guide 51 gives the principles of this hazard analysis approach, while ISO/TR 12100 (2003) *Safety of Machinery* (which is the same as EN 292) provides an extensive checklist, particularly of mechanical hazards, applicable to more than just machinery. Similarly, CEN TR 13387 (2004) offers model hazard analyses and safety requirements that are applicable to the safety of young children in product sectors other than the child care articles for which it was written. This covers chemical, fire, and thermal hazards as well as mechanical ones. The tests and requirements in toys standards (particularly EN 71 Part 1 2005) are also frequently applied, voluntarily, to a wider range of consumer products than the limits of their scope would imply.

The structure of electrical standards means that fairly comprehensive electrical safety requirements, applicable to most types of battery or mains electrically powered consumer products, are set out formally in IEC 60335 Part 1 (2006) for household products and in IEC 60745 Part 1 (2006) for powered hand tools. Electromagnetic radiation, noise, nuclear, biological hazards, active chemicals, and vehicles used on the public highway are all usually subject to national or regional regulations. The ergonomics standards described in Section 8.5 are, of course, applicable to many consumer products.

8.6.4 Standards in the Future

The nature of standards and how they are used by designers is changing with the development of more "generic" standards and guides that address hazards and consider user needs. Designers will need to use them as tools in their design activities rather than looking to them as prescriptive descriptions of permitted materials, construction methods, and gap sizes. Such information will still be necessary but not sufficient to ensure products are safe, convenient, and usable by all.

Designers will also need to look to the standards that help to ensure that quality is present throughout design management, production, and communication with the consumer.

8.7 SOURCES OF INFORMATION

The following websites were current at the time of writing and will provide access to many of the standards and guides mentioned in the text:

The International Ergonomics Association (IEA): www.iea.cc/

IHS Standards Store: www.global.ihs.com

Perinorm: www.perinorm.com

The International Organization for Standardization: www.iso.org

New work on safety standards for consumer products: http://www.iso.org/iso/pressrelease.htm?refid=Ref1268

The International Telecommunications Union (ITU): www.itu.int/

The Worldwide Web Consortium (W3): www.w3.org
The European Union's Europa Website: http://europa.eu/
The European Committee for Standardization (CEN): www.cen.eu/
The European Committee for Electrotechnical Standardization (CENELEC): www.cenelec.org
The European Telecommunications Institute (ETSI): www.etsi.org
The American National Standards Institute (ANSI): www.ansi.org
United Nations Economic Committee for Europe – Vehicle Regulations: http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29glob_candidate.html
The World Standards Services Network (WSSN): http://www.wssn.net/WSSN/index.html

REFERENCES

ANEC, 2003. *Consumer requirements in standardisation relating to the information society.* Brussels: European Association for the Co-ordination of Consumer Representation in Standardisation.

BS 7000-6. 2005. *Design management systems. Managing inclusive design.* Guide. London: British Standards Institution.

CEN. 2006. Leaflet: You're living it! 24 hours with European Standards. Brussels: European Committee for Standardization.

CEN/CENELEC Guide 6. 2002. *Guidelines for standards developers to address the needs of older persons and persons with disabilities*. Brussels: European Committee for Standardization.

CEN/CENELEC Guide 11. 2006. *Product information relevant to consumers – Guidelines for standards developers*. Brussels: European Committee for Standardization.

CEN/CENELEC Guide 14. 2009. *Child safety – Guidance for its inclusion in standards.* Brussels: European Committee for Standardization.

CEN TR 13387. 2004. *Child care and use articles – general and common safety guidelines.* Brussels: European Committee for Standardization.

ECE Reg 44. 1998 plus amendments to 2005. Uniform provisions concerning the approval of restraining devices for child occupants of power-driven vehicles ("child restraint system"). United Nations Economic Commission for Europe. http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29glob_candidate.html.

EN 71 Part 1: 2005. *Safety of toys – Part 1: Mechanical and physical properties*. Brussels: European Committee for Standardization.

Fisk, A.D., Rogers, W.A., Charness, N., Czaja, S.J., and Sharit, J. 2004. *Designing for Older Adults*. Florida: CRC Press.

General Product Safety Directive. 2001. (2001/95/EC). Brussels: European Commission.

Hood, C., and Jones, D.K.C. (eds). 1996. *Accident and Design*. London: UCL Press.

IEC 60335 Part 1. 2006. *Household and similar electrical appliances – Safety – Part 1: General requirements.* Geneva: International Electrotechnical Commission.

IEC 60745 Part 1. 2006. *Hand-held motor-operated electric tools – Safety – Part 1: General requirements*. Geneva: International Electrotechnical Commission.

IEC 62079. 2001. *Preparation of Instructions – Structuring, content and presentation.* International Electrotechnical Committee.

ISO. 2007. Overview of ISO. http://www.iso.org/iso/en/aboutiso/introduction/index.html#one.

ISO 6385. 2004. *Ergonomics principles in the design of work systems.* Geneva: International Organization for Standardization.

ISO 7000. 2004. *Graphical symbols for use on equipment – Index and synopsis.* Geneva: International Organization for Standardization.

ISO 9241 series (various dates from 1992 to 2006). Parts 1 to 17 on *Ergonomic requirements for office work with visual display terminals (VDTs)*. International Organization for Standardization.

ISO 13407. 1999. *Human-centred design processes for interactive systems*. Geneva: International Organization for Standardization.

ISO 20282: Part 1. 2006. *Ease of operation of everyday products – Part 1: Design requirements for context of use and user characteristics.* Geneva: International Organization for Standardization.

ISO 20282: Part 2. 2006. *Ease of operation of everyday products – Part 2: Test methods for walk-up-and-use products.* Geneva: International Organization for Standardization.

ISO/PAS 20282: Part 3. 2007. *Ease of operation of everyday products – Part 3: Test method for consumer products*. Geneva: International Organization for Standardization.

ISO/PAS 20282: Part 4. 2007. *Ease of operation of everyday products – Part 4: Test method for installation.* Geneva: International Organization for Standardization.

ISO 26800: under development. *Ergonomics – General approach, principles and concepts*. Geneva: International Organization for Standardization.

ISO/IEC Guide 14. 2003. *Purchase information on goods and services intended for consumers.* Geneva: International Organization for Standardization.

ISO/IEC Guide 37. 1995 (under revision). *Instructions for use of products of consumer interest.* Geneva: International Organization for Standardization.

ISO/IEC Guide 41. 2003. *Packaging – Recommendations for addressing consumer needs.* Geneva: International Organization for Standardization.

ISO/IEC Guide 50. 2002. *Safety aspects – Guidelines for child safety*. Geneva: International Organization for Standardization.

ISO/IEC Guide 51. 1999. *Safety aspects – Guidelines for their inclusion in standards.* Geneva: International Organization for Standardization.

ISO/IEC Guide 71. 2001. *Guidelines for standards developers to address the needs of older persons and persons with disabilities.* Geneva: International Organization for Standardization.

ISO/IEC Guide 74. 2004. *Graphical symbols – Technical guidelines for the consideration of consumers' needs.* Geneva: International Organization for Standardization.

ISO/IEC Policy Statement. 2000. *Addressing the needs of older persons and people with disabilities in standardization work*. Geneva: International Organization for Standardization. http://www.iso.org/iso/iso_iec_gen3_2000-en.pdf.

ISO TR 22411. 2008. *Ergonomic data and ergonomic guidelines for the application of ISO/IEC Guide 71 to products and services to address the needs of older persons and persons with disabilities.* Geneva: International Organization for Standardization.

ISO TR 12100. 2003. *Safety of Machinery.* Geneva: International Organization for Standardization.

Karwowski, W. (ed.) 2006. *Handbook of Standards and Guidelines in Ergonomics and Human Factors.* Mahwah, NJ: Lawrence Erlbaum.

Norris, B., and Wilson, J.R. 1997. *Designing Safety into Products*. Nottingham: University of Nottingham.

Priest, H.A., Wilson, A., and Salas, E. 2006. National standardization efforts in ergonomics and human factors. In *Handbook of Standards and Guidelines in Ergonomics and Human Factors*, ed. W. Karwowski, 111–31. Mahwah, NJ: Lawrence Erlbaum.

Salvendy, G., and China, P.R. 2006. Foreword. In *Handbook of Standards and Guidelines in Ergonomics and Human Factors*, ed. W. Karwowski, ix. Mahwah, NJ: Lawrence Erlbaum.

Spivak, S.M., and Bremmer, F.C. 2001. *Standardization Essentials: Principles and Practice*. New York: Dekker.

Wettig, J. 2002. New developments in standardization in the past 15 years – product versus process related standards. *Safety Science* 40 (1–4): 51–56.

9 Addressing Human Factors and Ergonomics in Design Process, Product Life Cycle, and Innovation: Trends in Consumer Product Design

Gabriel García Acosta, Karen Lange Morales, David Ernesto Puentes Lagos, and Manuel Ricardo Ruiz Ortiz

CONTENTS

9.1 INTRODUCTION

Globalization, technological complexity, the growth of more mature markets demanding differentiated or high-quality products, and the pressure of competition to reduce time and cut development costs have been leading to a broader application of methods and techniques that address human factors in different ways. As a result, a large number of methods and techniques have been developed, each offering different and complementary approaches that enhance the understanding of design requirements relating to people. In line with this, the aim of this chapter is to present an overall view of current trends addressing ergonomic and human factors in consumer product design, so that the advantages, disadvantages, and challenges facing researchers and practitioners can be understood. A further goal is to locate the pertinent application of methods and techniques over the whole product life cycle (PLC), with respect to design and innovation processes.

9.2 TECHNOLOGY OF CONSUMER PRODUCT DESIGN AND DEVELOPMENT

Consumer product design and development is a field that involves many disciplines, because of the diverse knowledge that is required throughout the whole process chain. The disciplines that make a major contribution to this knowledge include design, engineering, management, marketing, and ergonomics. Each discipline uses information, methods, and techniques sometimes developed in other fields or sciences, and in this way new knowledge is obtained. As a result of enhancing, integrating, and applying new knowledge, new methods and techniques are generated. Although the different disciplines can be quite different, most of them have common objectives, namely, reducing design and development time, avoiding or reducing human error, improving performance during product life span, fostering people's participation in the defining of design requirements, improving the quality of people's life, and building solid user knowledge.

This technology is getting stronger as a result of the common purposes identified in the disciplines involved and improved methods and techniques achieved through research by practitioners in this field (Puentes Lagos 2009). These methods and techniques are thus used not only by the professionals who developed them, but also by professionals in other disciplines that play a role throughout the whole design and development process. Consequently, tools and knowledge are generated and spread, nourished and consolidated, by new research and innovations in the goods and services market. Two dimensions in this changing, dynamic consumer product design and development technology play a decisive role: people and project.

9.2.1 People

Both ergonomics and design have an anthropocentric focus. According to Fulton Suri (2007), people have always been involved in the design process (DP). However, the key points are how designers understand human beings, and what role human beings play in the DP. People assume different roles when using technical artifacts to meet their needs. As stated by Kroes (2001), technical artifacts are at the same time a physical construction and a social construction: they have a dual ontological nature. Similarly, designers and ergonomists can approach people from different perspectives, namely, to observe people (or "design for"), to participate with people (or "design with"), and to empower people (or "design by") (Fulton Suri 2007), and these perspectives should be taken on board consciously by designers and ergonomists, recognizing people's needs as intentional actions—use—(Kroes 2001), in order to tackle consumer product design and development.

9.2.1.1 To Observe

Under this perspective, designers and ergonomists work observing people, in order to capture their needs and requirements. Here, people act as a source, and their needs are inferred by designers and ergonomists (Fulton Suri 2007). Many observation techniques and methods are used for acquiring input, process, and verification data. Designers and ergonomists use this data as if they were the experts on the activity, making decisions to configure the products. The generated data should be handled in an efficient and integrated way, so that they can be used in the different consumer product design and development phases.

9.2.1.2 To Participate With

Here, people, along with the designer and the ergonomist, are considered to be members of the work team in a participative approach (Noro and Imada 1991). With this approach, designers learn with people and help to translate their needs (Fulton Suri 2007). This perspective aims to build first-hand knowledge with people about their needs, and how these can be met with products. Points, such as their desires, feelings, and knowledge, result in greater reliability in the consumer product design and development process.

9.2.1.3 To Get Involved

The third perspective refers to empowering people so that they can recognize and meet their own needs. It is assumed here that people always aim to meet their needs, therefore they should be integrated into and play a leading role in the design team (Fulton Suri 2007). The role of the designer and the ergonomist becomes one of cooperating in people's creative process. With this latter perspective, people are empowered to meet their needs and conceive alternative solutions throughout the whole DP.

9.2.2 Project

The numerous disciplines involved in consumer product design and development (i.e., engineering, design, management, etc.) share the common feature of future thought. Consequently, and especially in the case of engineering and design, they build a set of representations of possible consumer product futures, using thought models fed by many symbols, meanings, and formal representations (Goel and Pirolli 1992). In line with this, all share the feature of working with methodologies that allow them to define how the variables analyzed will possibly behave in the future. Based on these variables, main decisions can be made that define product characteristics.

However, disciplines working on consumer product design can have different interests, and their vision of the future will therefore depend on each particular interest. Three perspectives are presented in the following paragraphs: PLC, DP, and innovation-to-cash cycle (ICC).

9.2.2.1 Product Life Cycle

This is a common concept used in concurrent engineering, and it refers to all the stages that a product (considered as an individual object) has to go through from creation to the end of its life. PLC covers the initial stages in organizations that produce the artifacts (i.e., definition, design and development, production, packaging, and transport), until they are sold or transferred to the user through distribution and marketing channels. It also includes post-sale stages that concern the user or collectives, such as use, maintenance, re-use, recycling, dismantling, and final disposal (Riba Romeva 2002).

9.2.2.2 Design Process

A DP is a future thought structure aimed at solving a problem (Cross 2003). There are many different approaches to dealing with a DP, although fundamental stages include planning, in order to identify priorities and draw up a plan of action; analyzing, for structuring requirements; concept design, relating to developing problem-solving concepts; detail design, where product specifications are established; simulation/testing and pre-series evaluation, in order to assess technical and human requirements.

9.2.2.3 Innovation-to-Cash Cycle

This model was developed by the Boston Consulting Group. Capital investment return time in the product DP is another way of viewing the future. Its interest lies in identifying product maturity, taking market insertion and acceptance into consideration. This vision makes it possible to differentiate between the various stages in a product's life, so that decisions that will extend product maturity time on the market can be made. Moreover, it allows product portfolios to be located on the basis of their life as a business strategy (Andrew and Dalens 2004).

In line with these approaches, Figure 9.1 shows tasks on the vertical axis and time on the horizontal axis, thereby allowing a comparison to be made between the different future visions of each approach. However, it is important to mention that while the three perspectives give a linear representation of the aforementioned processes, they also acknowledge the existence of deep implications with respect to circular and iterative thought (Jimenez Narváez 2000).

9.3 GENERAL TRENDS IN DESIGN FOR PEOPLE

The importance of involving people in the DP in order to understand their needs and values has been pointed out by many authors and in many fields. Many research papers and practical experiences

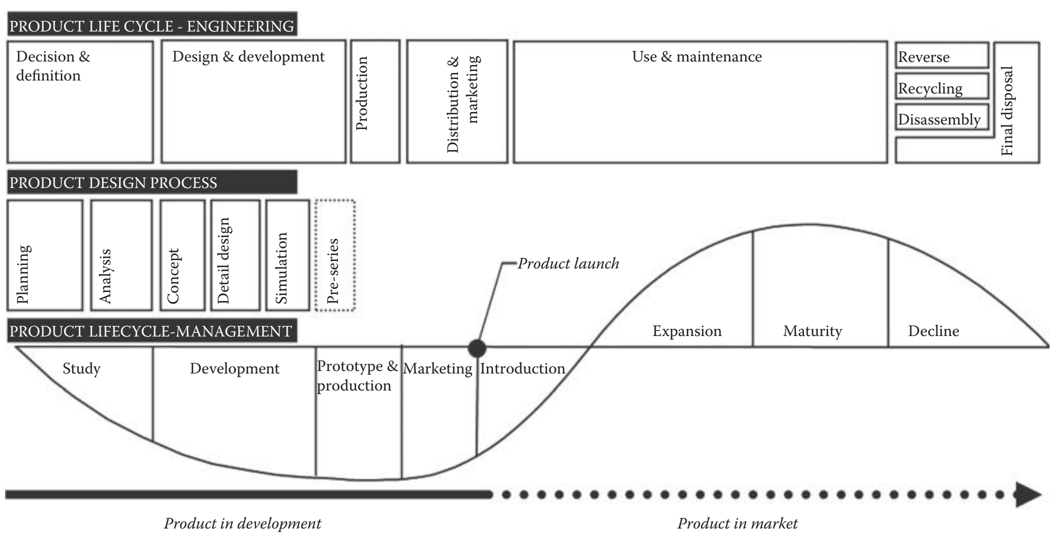


FIGURE 9.1 PLC/DP/ICC scheme. (Adapted from Riba Romeva, C.R., *Diseño concurrente,* Edicions UPC, Barcelona, 2002; Andrew, J.P. and Dalens, F. Innovation to cash: Orchestrating in the consumer industry. Boston Consulting Group, Inc., 2004. http://www.bcg.com/documents/file14296.pdf.)

have been published, dealing with anthropocentric design used for products and services design and development. In line with this, a systematic review of state-of-the-art publications was undertaken (García Acosta 2009). This review formed the basis for establishing the trends detailed below. After each trend was defined, a brief historical review was carried out, in order to gain a better understanding of the core dimensions of each trend.

Five main trends were established, namely, collaborative design, user-centered design (UCD), usability, universal design, and experience-based design (EBD). Transverse to these main trends, other approaches, methods, or techniques were recognized, such as participatory design, ethnography, and scenario building. These approaches could not be classified as belonging to a particular trend, since they could be found in many of them. This is why they were placed in a separate group, for explanation purposes only, since in practice they contribute to many of the particular design trends.

Finally, it should be stressed that the trends complement each other in many cases and their borders overlap. Each particular project is built using one or more trends, sometimes in a seamless combination. However, it is important to understand the concepts, advantages, and disadvantages of each trend, in order to improve the methodological assembly (García Acosta et al. 2009) that typically arises in each particular project.

9.3.1 Collaborative Design

9.3.1.1 Aims, Concepts, and Focus

This is a fast-growing trend due to circumstances like greater complexity in product systems such as vehicles (i.e., more components, more functions, and more associated technologies) and the diversification and globalization of production systems. Another aspect that contributes to this growth is the change of perspective, according to which every product is conceived as a service, because according to this approach, a company has to support its customers throughout the PLC. In line with this, collaborative design aims to (a) increase variable convergence, so that robust decisions can be made in definition phases; (b) add disciplinary efforts supported by communication and prototype technologies, in order to obtain designs and developments with more quality and functional integration; (c) achieve better production processes and technology selection, in order to reduce production time and costs and to enhance productivity, and therefore competitiveness; (d) build up distribution and marketing networks, thereby promoting a more active participation in product conception and innovation processes; and (e) integrate with other fields or approaches, such as usability, UCD, or EBD (Nieters and Williams 2007) in order to encourage permanent feedback with respect to new needs or improvements made by users, including maintenance, reuse, recycling, and final disposal.

One feature of this trend is the use of an interdisciplinary and multi-disciplinary approach, which integrates qualitative and quantitative methodologies in product development.

Collaborative design application is boosted by information and computer technologies (ICTs). These allow for networking in real time and in a ubiquitous manner and, at the same time, mean that efforts can be combined for solving design problems and making production processes more efficient. Three main working environments are recognized, namely, outsourcing, peer to peer work, and clusters. This makes designing the DPs more complicated, something that should be considered when it comes to simplifying dynamic decision making (Fathianathan and Panchal 2009).

Collaborative design can be viewed from three interdependent perspectives: emerging scenarios, the stakeholders' role, and decision making. Five scenarios can be identified, namely, work between companies, university–state relationship, state–community relationship, work within multinational companies (headquarters), and university–private sector relationship (Vogel 2008). Stakeholders can play several roles, such as developer, supplier, producer, distributor, vendor, consumer, or user. All roles, including their respective knowledge and information, have to be taken into account in decision-making processes throughout the whole DPs.

One of the main conceptual discussion points is the need to base ongoing work on new principles and paradigms, something that is necessary in a globalized design scheme. Another important discussion topic is creating a respectful environment, one where all types of knowledge are valued. A cooperation environment should stimulate interaction, integration, and distribution tasks, and facilitate coordination, negotiation, and discussion. Aspects that can be stressed include the synergic combination of technologies, engineering and management, and the role of experts.

9.3.1.2 Methods and Approaches

Many studies propose developing, enhancing, improving, or validating methods, models, platforms, or software. These programs, models, or platforms have the common purpose of making collaborative networking easier with respect to communication, decision making, verification, simulation, disseminating documentation and knowledge, distributing and integrating tasks, and forming intranet work teams. Other concerns include (a) building methods with a reference framework for analysis, design, and product development, such as knowledge-based finite element analysis, information maps and routes for supporting decision making, and product information models that allow for the cooperative establishment of design parameters and requirements along with a definition of product components; (b) integrating knowledge management and design on the basis of an axiomatic breakdown and an ontology-based knowledge model (Hou, Su, and Wang 2008); and (c) developing behavior-based models that improve design planning. In short, the main concern is to use and boost ICTs in order to reduce DP time and strengthen multi-disciplinary work throughout the PLC (Shen, Hao, and Li 2008).

Considering how time is handled, two approaches can be identified, namely, an asynchronous approach, which refers to sequential information and decision making, and a synchronous approach, conceived as simultaneous work aimed at reducing time (Eng et al. 2008).

As far as the participation scale of collaborative work process is concerned, one classification identifies three levels: among individuals (also known as co-design), collective level, and corporate level. Other authors have built a taxonomic structure based on six factors, namely, team make-up, communication, distribution, nature of the problem, information, and design approach (Ostergaard and Summers 2009).

9.3.1.3 Advantages, Disadvantages, and Challenges

Collaborative design allows experience, information, and knowledge to be added to all PLC phases, and this in turn permits a multi-disciplinary construction of requirements. At the same time, it strengthens real time networking, thereby enhancing innovation opportunities throughout the PLC. Similarly, this approach helps enhance and improve documentation processes, thereby supporting knowledge management.

However, teams following this trend have to face and solve various challenges. On the one hand, the interdisciplinary and multi-disciplinary approach that typifies collaborative design establishes new communication, agreement, and consensus challenges for professionals with different education and training (van Tooren and La Rocca 2008). On the other hand, despite its purpose of making decision making easier in complex design situations, one potential pitfall is that it complicates or prolongs decision making, due to things like coordination problems or disciplinary language differences. In order to overcome this, time is therefore needed to generate an appropriate working environment between working groups. In line with this, much work is done on software development and adaptation for interchanging information between work teams (Sivakumar and Nakata 2003): compatibility, flexibility, scalability, sustainability, and efficiency seem to be the guidelines in this process.

9.3.1.4 Application to Consumer Product Design

Collaborative design has a very broad sphere of application, and can be understood in two main domains, namely, the business domain and the project domain. Furthermore, both these domains can be related to three principles: (i) applying process management, (ii) adopting supply chain management, and (iii) establishing value frameworks. This trend is being extended from collaborative networking between sectors that form local clusters (Yu and Jing 2008) to industrial macroprojects applying the latest technology, where different companies, with their worldwide bases, work together (Goldin, Venneri, and Noor 1999). Another important application is in networking between academic research groups or institutes and industrial sectors or companies (Fanucci et al. 2007). Urban space transformation, public transport, and new citizen information services are other applications where this trend is proving very useful.

9.4 USER-CENTERED DESIGN

9.4.1 Aims, Concepts, and Focus

Historically, some authors have suggested, from different perspectives, the importance of involving the user in the DP (Damodaran 1983; Pejtersen 1984; Brown and Newman 1985). Norman and Draper (1986) defined the notion of user-centered system design directly linked to the user-computer system interface, thereby consolidating a trend previously explored from the human factor and ergonomics viewpoint, called human-computer interaction (HCI). Subsequently, Norman (1988) expanded the UCD concept to everyday objects, which has resulted in a wide range of approaches and applications. Other authors have introduced further applications of UCD, such as human-centered design (HCD), recognized in diverse fields of product design.

This trend is a design and product engineering stream that focuses its efforts on generating knowledge about human factors and using it for product development. According to ISO 13407, HCD is defined as "the active involvement of users and a clear understanding of user and task requirements; an appropriate allocation of functions between users and technology; the iteration of design solutions; multi-disciplinary design."

According to how the trend has so far been recognized, UCD can currently be said to be the generic way to identify all studies derived from human factors and ergonomics, based on physiology, experimental psychology (experimentation and simulation), cognitive science, and anthropology (anthropometrics), oriented toward product/service design. Quite apart from these elements, UCD goes further in that it breaks into and finds support in other fields of knowledge, such as social science (ethnology), new technologies, ICTs (virtual reality), and paradigms such as participatory paradigm and constructivism (Guba and Lincoln 2005).

Eason (1995) introduced two design approaches, namely, design for the user and design by the user. Fulton Suri (2007) introduced three design approaches, namely, design for the user, referring to the process where the designer interprets what the user wants, design with the user, where designers and users are engaged in a permanent dialogue and feedback during the DP, and design by the user, where the whole DP is carried out by the user, who is an expert in this subject, as in some very specialized sports devices and accessories.

In the PLC, UCD is used for generating useful information, so that objective decisions can be made and design specifications defined without the designer's prejudices interfering (Kwon et al. 1999).

Its origins are related to ergonomics, from which it has taken the initial simulation and interface trials structure (human–machine) based on activities, tasks, and uses. The initial simulation protocols were centered on an adequate and safe performance, the aim being to avoid errors or risks. Some consumer product case studies show simulation processes with virtual humans evaluating the complexity of the users' anthropometric variability, safety, and product ergonomics. Currently, the application has been extended to the development of haptic user interfaces (Bjelland and Tangeland 2007).

UCD is working on a deep understanding of user needs, goals, and sensations, with a view to ensuring total satisfaction, by bringing users in from the early design stages, in accordance with usability principles (Ames 2001). Other studies show prospective helping relationships, mainly to think about new product concepts, according to social trends and company strategies (Salovaara and Mannonen 2005).

In short, UCD attempts to find out users' needs based on behavioral science and social science, unlike technology-centered design, which starts with the artifact and aims to advance from the basis of applied sciences like cybernetics and engineering (Krippendorff 2007).

9.4.2 Methods and Approaches

The current UCD focus has gradually changed the laboratory and experimental atmosphere (isolated and controlled) into fieldwork (Greene et al. 2003) based on social sciences such as ethology and ethnology, with scenario construction methodologies used for capturing product requirements.

UCD continues to be focused on models and prototypes as ways to develop knowledge about interaction, not only from the physical dimension, but also considering cognitive interaction: virtual models and prototypes and augmented reality, for instance, or the understanding of spatial allocations, going from static to multi-dimensional models, which improve visualization by non-expert users.

With regard to user-centered methodologies, three relevant ones used in some companies can be recognized: designer education and training, process standardization and amendments, and user interface evaluation by experts (Kobayashi, Miyamoto, and Komatsu 2009). These techniques are complemented at the production stage by fast multi-layer prototyping systems. At the distribution and marketing stage, some focuses take customer needs into account by comparing them with the user's visions, based on simulation techniques such as renderings of the product's features.

9.4.3 Advantages, Disadvantages, and Challenges

Some authors talk of the benefits and challenges of involving users from early stages in the design and development process and taking them as a primary source of reliable information (Kujala 2003; Kujala and Mantyla 2000). Likewise, these authors point out that through constant simulation and verification, using techniques like virtual reality immersion (CAVE) and virtual prototyping (VP), related to the traditional computer-assisted device (CAD), product design and development time and cost can be considerably reduced because the DP is provided with feedback in the early stages of conception, in the form of information about users' experience with virtual devices and environments (Liukkunen et al. 2008).

UCD is considered by some authors to be a business strategy that could form part of companies' top management, as long as the goals expected by consumers can be made explicit. More than a simple practice focused on design teams, UCD should be part of companies' organizational culture. UCD can be regarded even as a risk management tool, since if the product can be evaluated and validated in the early stages of conception, it minimizes the risks of design and development costs (Skelton and Thamhain 2005).

The consumer product DP is complex, since it has to make users' requirements and abilities compatible, in terms of use and function, with the qualities attributable to products. This sets a challenge for design teams and implies cooperation between various disciplines throughout the DP. One thing that is both a disadvantage and a challenge at the same time, is maintaining a common basis for communication, even allowing for the differences in perception of use and manipulation of products between users and designers.

9.4.4 Applications to Consumer Product Design

The main application is to generate prompt knowledge for establishing the diverse user requirements and perceptions, based on a mixture of qualitative and quantitative techniques (Karapanos and Martens 2007), and it is at this point that the relationship with usability knowledge takes place, forming a basis for participative design. Along with usability and other fields, UCD is part of what some authors call the future science of service (Hirata and Yamaoka 2007).

9.5 USABILITY

9.5.1 Aims, Concepts, and Focus

The concept of usability was introduced by Shackel in the early eighties. Several researchers, such as Miller (1971) and Bennett (1979) in the field of computer system design and interfaces with humans, backed Shackel's work, which attempted to change from traditionally DP centered on the IT-related form of operation (i.e., computers), to the design for usability (i.e., people) (Shackel 1986). This notion spread in the nineties after Jakob Nielsen (1993) launched his conceptual proposals. Nielsen proposed that usability be developed on the basis of five principles: easy to learn, efficient to use, easy to remember, few errors, and subjectively pleasing. Meanwhile, a model was developed consisting of three components, to address the change in performance on the basis of repetition. This model was later expanded to have five components (Jordan 1994).

Usability implies knowing the user, their characteristics, tasks, and environments (March 1994). In its broadest sense, it is a field of knowledge that attempts to identify interaction problems when products or digital platforms are being used, principally in the fields of ICTs, with a view to making them easier to use. According to ISO 9241-11, usability diagnoses problems in technologies, their languages, users' knowledge, and values and use contexts, in order to predict levels of effectiveness, efficiency, and satisfaction.

The importance of this dimension of consumer product design was first considered in the early nineties at companies like Thomson Consumer Electronics, Apple Computer, and Northern Telecom (March 1994). Nowadays, the importance of its application for making products easier to use, more comprehensible, accessible, and more comfortable is recognized in general, and in different contexts.

Currently, usability is no longer restricted to HCI or ICTs, and is applied in a wide range of product development fields. Usability encompasses a wide body of knowledge in something that has been called "usability engineering," looking at solving user interaction problems, product risk management, and quality management (Ketola 2000).

As far as application in PLC is concerned, usability makes a key contribution in the initial stage when factors, variables, and design requirements are being decided and defined. If the usability criteria that come from the user's requirements for performing tasks or activities are taken into consideration, design and development time will be reduced. In addition, costs will be reduced, mainly those relating to verification. However, the utilization of usability should be reflected in testing protocols throughout the product design and development stages. Now, if we adhere strictly to the concept that the more quality a product offers, the more usable it is, we need to enter the debate about a greater product utility participation; in other words, life span, obsolescence, and end of life cycle (Babbar, Behara, and White 2002).

Another important conceptual criterion is that the structuring of variables and the concept of usability itself depend on the product that is to be assessed. For instance, if we refer to footwear, a key dimension in user satisfaction is comfort, while if a website interface is being designed, key dimensions include accessibility and information legibility.

This relative condition causes problems when it comes to generalizing about evaluation criteria and not depending on experts' opinions, as some researchers have tried to do. For this reason, only now are more generic criteria being established based on interaction categories and ease of use and user satisfaction demands, but reaching a universal consensus is very difficult. Moreover, some studies show intercultural differences in the understanding of and concern for use variables, which makes the attempt to universalize them difficult (Frandsen-Thorlacius et al. 2009).

Although there are intercultural differences that make certain aspects of universality difficult, one view of the universality of usability has been structured from another perspective, the notion of inclusion. The concept of universal usability has been proposed. It comes from the work of Vanderheiden and Stephanidis, and focuses on three areas: user diversity, technology diversity, and bridging the gap between what users know and what they need to know (Lazar 2007).

The fundamental focus continues to be ease of use when interacting with any device, object, or information. This facility can be addressed from an understanding of user needs and requirements in the physical, cognitive, and emotional dimensions, which are to be understood as complementary and interdependent.

Finally, it is important to mention that companies in a globalized market, with complex consumer requirements and high technology development, identify day-by-day usability as being a strategic element in competitiveness, efficiency, differentiation, and good practice by integrating it throughout the different processes in the PLC, including its influence in the creation of values, brand fidelity, and innovation (Lin and Luh 2009).

9.5.2 Methods and Approaches

Many methods and techniques are employed in usability, some of which have been taken directly from other disciplines or are adaptations, while others have been developed from specific instruments in order to deal with the field of usability. Especially in the software-intensive system and product field, the importance and implications of usability capability models (UCM) have been analyzed, based on a comprehensive approach using 11 different models (Jokela et al. 2006). Another important focus has been heuristic design and evaluation methods (Kamper 2002).

As far as focus is concerned, the empirical focus predominates, but there are also qualitative and quantitative methods. Studies that refer to qualitative approaches include Insider Action Research (IAR), which allows the researcher to be present and play an active role during most of the project development time, either as leader, as member of the design team, or as observer (Bjork and Ottosson 2007). There is a growing concern about quantitative approaches, as a way of making this field a more "objective" one: for example, statistical methods for the screening of variables as well as a relationship with techniques such as quality function deployment (QFD) and generation of usability indices.

Some studies show that a process has started to establish, under a number of classifications, groups of techniques and methods for recognizing usability applications in a particular part of a product's life cycle. The resulting process is a model that takes the form of a sequence of different cycles, called "The Wheel Process Model," as a usability engineering management system (Helms et al. 2006).

New methods and techniques are appearing, as well as the refining of older ones or transferring from other fields, especially from social sciences, an example being demography-focused questionnaires, usability questionnaires comparing the understanding of the whole and of individual components, the perceptual control theory, the visual representations method, or think-aloud protocols (George 2008).

9.5.3 Advantages, Disadvantages, and Challenges

For companies, usability has to go beyond the mere technical excellence of their products, and a fundamental directive is that products should be easy to use. This explains why usability is now recognized as a critical dimension of product quality. The user's physical, cognitive, and emotional needs can be gathered and correlated through affinity maps or diagrams, in order to help product design directors find out and meet user needs (Babbar, Behara, and White 2002).

The contradiction that has been detected is that when attempts are made to generalize, systematize, and universally apply processes, techniques, and methods, they lose their flexibility, adaptation or customization capability, coverage, and the quality of being complete. The current discussion with regard to the diversity of methods is therefore that each product type requires tailored usability engineering. However, the aim is to draw up a general framework where product engineers and designers can find specific techniques and existing or new methods and activities to apply in the PLC under "good usability practice" criteria.

The main conceptual concern about usability that has existed for 20 years is to define it explicitly and measure it objectively, so that improvements can be made to interface design, while observing and evaluating the different parts as components of a whole. To this end, the following points should also be taken into consideration: user knowledge and experience, characteristics, tasks or activities, and the use environment and context. One of the main challenges is how to raise awareness of the role of the designer in a process that is participative and includes the understanding of usability in relation to his/her knowledge, experience, abilities, and context. In this respect, certain studies point to the cross-cultural differences in applying usability and its implications. Another challenge that arises from the new design practices and open, free development is to not overlook the importance of including usability in the development of FLOSS software, in order to balance the development by private companies (Paul 2009).

Finally, the interdependence of how mature an organization is and the application of usability in the whole concurrent engineering cycle should be pointed out, as this leads to a series of challenges that have yet to be resolved if a product development culture is to be generated within organizations (Ketola 2000).

9.5.4 Applications to Consumer Product Design

Three major application dimensions can be identified. The first is the computational, from traditional human–computer interaction and the development of Internet browsing systems to virtual reality and augmented reality. Usability has always been more applicable to ICTs, mainly privileging the interface and visual and aural feedback, to software devices and communication gadgets, and in the web. However, augmented reality is guiding studies toward multi-sensory, including tactile, interaction (Ha, Chang, and Woo 2007).

The second refers to product use with respect to manipulation efficiency and effectiveness, and analyzing and solving physical (operative) or cognitive (perceptive) interface problems, taking age-dependent ability and cognition differences into account. In line with this, cell phones, or communication and information devices, will continue to keep researchers' attention.

Another recent sphere of usability application in products/services is information search, comprehension of messages, and the communication process. The design purpose of documentation and database management is related directly to the effectiveness and efficiency of the understanding and management of data, and by the satisfaction of the user in the control of the searched information.

9.6. UNIVERSAL DESIGN

9.6.1 Aims, Concepts, and Focus

This focus encompasses what is known as universal design, design for all, and inclusive design, and its fundamental purpose is the design of systems, products, services, and environments that can be used by the majority of people, without adaptations or special designs. More than a trend, it is considered to be an enduring design focus, one that assumes the range of human abilities as something ordinary, not special (Ostroff 2001). Universal design has its origins in a series of legislative movements in favor of social inclusion, as well as in demographic changes (i.e., an increase in population longevity).

Of all the trends analyzed, universal design is undoubtedly one of major importance that has a big social impact, because social inclusion is in its core proposal (i.e., social equality). Perhaps Ricardo Becerra Sáenz's phrases "it is normal to be different" and "it is abnormal to be indifferent" (Lange Morales and Becerra Sáenz 2007) substantially summarize the fundamentals of this philosophy.

It starts out by accepting that human variability is a normal characteristic of the human being and ends up by adopting an ethical posture toward the barriers and exclusion generated by the design of policies, systems, spaces, products, and services that do not take such normal human variability into account.

The Northern Carolina University "Center for Universal Design" formulated seven principles (Connell et al. 1997) in order to guide both product evaluation and the DP, thereby educating designers and consumers in the characteristics of more usable products and environments. These principles are equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and size and space for approach and use. Usability and safety criteria are thus included to a great extent, the aim being to improve quality of life and utility for everybody.

Much of universal design practice is inspired by the situation of people with disabilities, as well as by people with special needs, and taking aspects such as age, physical and emotional fragility, limitations and disabilities, social role, and autonomy into consideration. Participation by and the experiences of such users are therefore favored when design requirements and specifications are being defined, and throughout the research and development process.

One major issue addressed refers to the concepts of inclusion and exclusion. In this respect, the "Inclusive Design Cube" (Clarkson et al. 2000) is a model that enables not only those who are being included but also those who are being excluded to be visualized. Moreover, inclusion and exclusion criteria occur at different levels, such as physical, cognitive, social, etc.

Another aspect of great interest is stigma, and its relationship to product and service design. Most products that are designed to correct a disability provide a response that is as discrete as possible and tend to camouflage the "different" condition. Thus, this trend gets away from concepts such as fashion, which could enrich products from the aesthetic point of view and help transform prejudice and overcome the stigma (Pullin 2007).

Accessibility has been widely addressed, and significant progress has been made in it, in legislative terms. Accessibility relates to being able to go somewhere or to get something. The first sense refers to freedom of movement and the elimination of physical barriers, while the second one refers to being able to learn and use some product. Environmental barriers are recognized as constituting a greater impediment to participation in society than functional limitations. This highlights the underlying importance of the design and the development of technological products and services, since design will determine whether certain groups, such as disabled people, can use them or not (Marincek 2007). In line with this, assistive technologies have played and will continue to play a leading role in the search for improving accessibility and usability, and providing greater autonomy and freedom to people with certain disabilities.

Much research in this field has concentrated on physical aspects, but more research is being conducted in the cognitive and cultural dimensions.

This is a field of knowledge that is consolidating and influencing the development of complex urban systems and projects like public transport systems and public utilities, which are directly related to the drawing-up of regulations and legislation on accessibility and the right to equality.

9.6.2 Methods and Approaches

As well as UCD, this trend makes use of usability methods and tools, and is also based on transverse methods such as scenarios, participative design, and ethnography. In addition, specific tools have been developed for applying or evaluating the extent to which universal design principles are being met, methods to understand user needs, and models for evaluating the current and potential product market, as in the case of the Inclusive Design Cube (Clarkson et al. 2000). Computer-based tools have also been constructed, such as digital human modeling (DHM) RAMSIS, to make it easier to manage and consider the anthropometric diversity of users, or HADRIAN (Human Anthropometric Data Requirements Investigation and Analysis), an inclusive design tool that provides accessible and applicable data for the virtual evaluation of tasks, and in this way simulates a real world user trial

(Marshall et al. 2010; Porter et al. 2004). Since including people with disability in the DP is a prime directive, the study of more inclusive methods is a further area of interest for research.

9.6.3 Advantages, Disadvantages, and Challenges

Besides contributing to social inclusion (i.e., to social equality), which is undoubtedly the biggest advantage of this focus, universal design can bring economic advantages to a country's health care and welfare systems. Some studies have shown that the development of home- and community-based systems for frail elderly people has led to a reduction in long-term care expenditure (Stuart and Weinrich 2001). On the other hand, in line with the inclusion achieved through universal design, the potential market for this worldwide-growing population is expanding.

Elderly population continues to be one of the major challenges, demanding further research (Crews and Zavotka 2006). Another challenge that needs to be overcome is the dichotomy between individualization and standardization. The human being is unique, so why should he/she use standard products? (Lange Morales 1997). Because product and service production systems respond to concepts of standardization, this is one of the main qualities that has permitted the serial and mass production of goods and services. However, it is this standardization that has, in many cases, excluded those who do not fit the "standard." In this respect, the fact that a product or service is accessible and usable by the largest number of users should not be deemed a universal and standardized response: the challenge lies in giving a unique design response for unique beings, one that is at the same time accessible to and suitable for everybody.

9.6.4 Consumer Product Design Applications

Universal design can be applied to all consumer products throughout the life cycle of the product, with special emphasis on all technologies geared to the elderly population, whose life expectancy is increasing due to the quality of life. Great interest can be seen in the application of universal design in education. There are also several examples of it being applied in mobility systems. ICTs and interface design are other fields where universal design has been applied, especially in products such as cell phones. Automated machines, digital set-up boxes, packaging, bathroom products, and waste receptacles are other published examples of its application.

It is applied essentially in the early stages of the PLC, when design specifications are being decided and defined. The main criterion is ease of use, so that any user in different physical and cognitive conditions can interact with the artifact. Test protocols at the design and development stage aim to ensure that the philosophy and principles of universal design are adhered to. If these principles have been followed rigorously, less work will need to be done at the production stage. However, there can be protocols to check that what was specified and determined throughout the series of verification stages is attained in the final product. Again, the inclusive design focus plays a key role in utilization and maintenance, because it is in the real world, with the final products, that the extent to which a product is inclusive can be verified and validated. Likewise, at the reuse, reutilization, or even extension of life cycle stage, the universal design focus has made contributions and opened up new fields of research, since the real or programmed obsolescence of a product is a topic of interest in this field, especially due to the implications on the social aspect of the technology dynamic and the efforts needed by the users to learn and gain a fast and efficient command of these technologies.

9.7 EXPERIENCE-BASED DESIGN

9.7.1 Aims, Concepts, and Focus

Industrial design has always taken care of aesthetic experience, beauty, the pleasure of using, enjoying, contemplating, or having a consumer product (Dorfles, Mora, and Cirici 1968). This pioneering and permanent approach to experience has been based on philosophy and the arts. But in the field of ergonomics and human factors, the emotional dimension and experience issues were overlooked for several years, as was the case with psychology until Victor Frank's works, and later those of Goleman (1995) and Gardner (1999). Today, EBD is gaining strength and can also be found in literature referred to as emotional design (ED) (Norman 2004), conceptually based on social sciences, which are paying more attention every day to the study of emotions and so-called emotional intelligence (EI).

As a brief review of background studies of emotions, the work by Leuner (1966), Kleinginna and Kleinginna (1981), and Payne (1985) should be recognized. The concept of emotion can be understood as a complex set of interactions between subjective and objective factors, mediated through biological systems. These interactions can provoke affective experiences (feelings, pleasure/displeasure), bring forth cognitive processes, initiate physiological adjustments to changing conditions; and frequently lead to expressive, adaptative and purposive behaviours (Kleinginna and Kleinginna 1981).

Another essential focus is that of Kansei engineering, developed in Japan by Mitsuo Nagamachi in the seventies. This approach incorporates the work on the semantic differential technique by Osgood in 1969 (Schutte et al. 2004), and seeks to incorporate the dimension of the consumer's feelings into the function and design of products (Nagamachi 2002).

Later, Peter Salovey and John D. Mayer established the fundamentals of EI, defining it as the ability to perceive and express emotion, assimilate emotion in thought, understand and reason with emotion, and regulate emotion in the self and others (Salovey and Mayer 1990). Subsequently, Daniel Goleman (1995) further consolidated the concepts and principles theoretically in his book *Emotional Intelligence*.

In the field of consumer product design, three streams can be identified. One refers to the authors talking about pleasurable products (Jordan 2000), hedonic design (Bonapace 1999), or affective design (Khalid 2006). Another stream is called emotional design (Norman 2004), and the third one is known as experience-based design (Margolin 1997). Although some authors use ED, affective design and hedonic design as synonyms, the distinction is made here, since the basic postulates for each of them are considered to be different.

For some authors, ED can be understood as an extension of usability, but for others, usability is insufficient; the notion of satisfaction has thus progressed from the functional level through the usability level to the pleasure level (Jordan 2000).

ED is understood as being the framework for analyzing products in a holistic way, through three levels at which people act: visceral, or the initial impact of the object's appearance; behavioral, which refers to the total experience (what he/she sees and feels) when using the product; and reflective, or how a person thinks and feels after using the product, and the image and message it communicates to others about his/her likes (Norman 2004).

As stated by Margolin, the experience-based focus is wider than the two focuses mentioned previously. The idea of experience contributes to a more holistic understanding of the idea of use. Previous experience is fundamental to face use; for this reason, learning how to use an object, and the time needed to do this are dependent on previous experience. A two-way benefit can thus be gained from experience. On the one hand as knowledge, and on the other hand as satisfaction (Margolin 1997). Furthermore, experience is more inclusive and integrating, as it implies eliminating the Cartesian body-mind separation and understanding a symbiosis between the user, his/her body, movement, the product, and the context (Rompay et al. 2005). This previous conception is being applied in research in order to understand how human experience influences people's understanding of product usability (Chamorro-Koc, Popovic, and Emmison 2009).

The main underlying concept in this trend is that people can contribute their experience (either past or current) to the use of or interaction with products. The aim is to go beyond traditional surveys through an intimate, close, and spontaneous relationship that allows the essential and experiential aspects of the person to be expressed in a multi-dimensional and multi-faceted way. In line with this, there is a need for the vision of the role of users to be permanently integrated on the basis of three interdependent premises: the building of collective and individual knowledge, the context of use and its cultural heritage, and conceiving human experience as an understanding of the use and its emotional states. This trio of concepts enables both social subjectivity and individual subjectivity to be captured.

Finally, with respect to PLC, some authors propose including an emotional needs dimension as input in the early stages of the product design and development process. In general, and according to the conceptual vastness stated, design for experience can be assimilated and be useful throughout the PLC (Khalid and Helander 2006).

9.7.2 Methods and Approaches

There are subjective and objective approaches, but the affective dimension is even more difficult to objectify, since a wide range of variables are integrated and, at the same time, many of the methods for measuring and evaluating emotions are not directly applicable to consumer product development (Khalid and Helander 2006).

Some authors point out limitations in psychological measurement methods and suggest using physiological measurement methods as a more objective way to measure user emotions (Jeong 2007). However, a common feature is to understand what the user experience is, measure it, and direct this experience toward the design and development of the product.

Other ICT-based tools have been formulated for integrating user experience using a method that takes the user's points of view, environmental points of view, and life cycle points of view into account (Yamazaki and Furuta 2007).

An emerging concept found in recent studies, which will have new methodological implications, is the use of hermeneutics for understanding experience. In other words, being able to reveal, interpret, and clarify subjects' actions and values, thus leading people's subjective experience into objective understanding. It is important to eliminate—or at least reduce and delimit—ambiguity in the interpretation of human actions or communications. Cultural knowledge should be a deductive-interpretative process of individuals and collectives heritage.

9.7.3 Advantages, Disadvantages, and Challenges

There are two concepts that constitute a challenge to approaching EBD holistically. On the one hand are the customer's emotions, the aesthetic appearance of the product, and the pleasure of using it. On the other hand are expressions of conduct, knowledge, thoughts, and feelings, which go together and are very difficult to separate. These concepts go beyond the idea of creating methods or techniques for measuring emotions in an "objective" way, and reduce a complex and rich field to a concern for the dominant positivist paradigm in the field of science (Jeong 2007).

"Experience-based design" is one of the latest streams to have appeared in the design and product development world, which sets out to understand the user from the emotional dimension. ED, or the design of experience, establishes connotations that lead to conceptual and epistemological difficulties, since strictly and rigorously speaking, neither emotions nor experience are designed; what is created or designed are the conditions (environments or products) to stimulate and generate emotions and experiences. Viewed from this perspective, the conceptual differences in this trend have not been made explicit, nor have they been rigorously addressed. This is why there is a need to make room for debate, so that the epistemological and ethical aspects can be clarified.

The precision and definition of concepts such as experience, needs, and emotions have been questioned. In this respect, some authors (Kaygan 2008) have started a debate that becomes fundamental and raises questions like whether we are moving toward the commercialization of emotions, or whether the right way is to approach or capture experiences from an ethic of use and the user, or what satisfaction is or how we understand it. It is a fact that emotions have an influence on how we interact with a product, but are there user needs that truly go beyond functionality and utility, related to emotions? Or is it an extreme aspect of the consumer focus to delve more deeply into the intimacy of consumers, to reveal aspects that keep them as customers?

9.7.4 Consumer Product Design Applications

The focus of this trend is centered on two aspects. The first refers to knowing the user's experience (i.e., the perceptions, feelings, sensations, emotional changes, pleasure, enjoyment, and wishes that people have and share in a collective). The second is managing the user's experience, based on UCD, usability, and collaborative design. It can be deduced that it is important to transfer user experience in order to boost product/service innovation processes (Bate and Robert 2006).

Fields of EBD application include human–computer interaction integration at the physical and cognitive level, virtual reality, augmented reality, ICTs, increased "good practice" culture, fast adoption of usability standards, prototypes with enriched information from low-fidelity paper prototypes, and product allocation, understood as being the process of modifying applications or products based on the requirements of a particular scenario.

9.8 TRANSVERSE APPROACHES, METHODS, AND TECHNIQUES

Focuses, methods, and techniques common to a number of trends were found. Some of these approaches are introduced in this section, namely, participatory design, ethnography, and scenarios/personas.

9.8.1 Participatory Design

Participatory design goes against the traditional DP, where the designer—due to his/her expertise—took care of defining and controlling the formulation of user requirements. Since the First Participatory Design Conference in Seattle (1990), which concentrated on computer systems, this focus has grown toward the design and development of products and services in general. Participatory design practice has diverse focuses and is not unified by a single theoretical corpus; for this reason some practitioners confuse it with the collaborative design trend, including co-design, as addressed above.

There are diverse experiences and applications. However, the same direction and distinctive spirit, which is characterized by a concern for a more humane, creative, and effective relationship among those involved in technology design and use, are recognized in the diversity of focuses.

9.8.2 Ethnographic Studies

Ethnography is an interpretative anthropology technique that is geared to understanding the ethnical-cultural and geographical-cultural differences between people or social groups, not from a silent or neutral observation (monologue), but as a dialogic practice, one that privileges "discourse" over "text" (Geertz and Clifford 1991). It is considered to be a tool that backs up the cultural relativism paradigm and constructionist perspective focus in social science.

The ethnographer is interested in understanding human behavior as reflected in the way of life of different communities. The designer is interested in designing artifacts that will support the activities of these communities (Blomberg et al. 1993). Ethnography is thus a methodological alternative for the design and development of consumer products, since it accesses people's everyday practices as members of a social group.

Some authors mention advertising and marketing as focal points of application for understanding acquisition trends by groups, thereby establishing differentiated marketing strategies, along with the design of complex interfaces, especially ones relating to verbal and visual languages, the cultural perception of the formal aesthetic qualities of products, usability evaluation, knowing the value judgments of consumers and identifying how users perceive and enjoy products, and including innovation in the product cycle for identifying user experiences as opportunities for innovation.

The information obtained through ethnographic studies is used by various anthropocentric design trends, especially at the PLC decision and definition stage, for gaining a less hypothetical specification of final user needs and requirements.

9.8.3 Scenario Building

Scenario building is a set of methods and techniques that are used in prospective structuring processes for foreseeing the best path that can be followed in a specific technological or social development. In design, it is a powerful exploration, prototyping, and communication tool (Fulton Suri and Marsh 2000). It is used for understanding the user's role during product design and development, and for this reason it is widely used in different trends.

Scenario building enables the environment to be modeled and simulated as a framework that contains factors related to market, technology, suppliers, distribution logistics and sale systems, economic conditions, and environmental requirements. Characters, contexts, and groups of activities are interlinked, thus making it easier to understand system complexity and dynamics, as well as the "use experience."

This method is complemented by the construction of personas, which provides contextual models that enrich the construction of requirements (Aoyama 2005).

Scenario building enables user needs to be characterized and looked into more deeply than purely functional needs. Success using this technique relies on the ability to make a script as rich as possible, taking into account the various features of the physical, social, and cultural environment in which the characters perform.

This method is used in PLC especially at the decision and definition, design and development, and utilization and maintenance stages. However, this tool could be used in any PLC stage, since it stimulates creativity and the generation of concepts on a platform that all assistants and creators share.

9.9 CONCLUSIONS

The diverse trends can be differentiated and understood in the consumer product design and development framework in light of their respective purposes. Collaborative design thus aims to coordinate, add to, share, and boost knowledge for solving more complex problems. UCD aims to understand human behavior as individuals and collectives, so as to make the functions of products more compatible with human actions. Usability seeks to go beyond the functional dimension and generate products that are easier to use, thereby increasing user satisfaction. Universal design sets out to provide inclusive and equitable access to products. And EBD aims to go beyond product functionality and usability and generate emotions through the use of objects. Transverse focuses and methods (i.e., participative design, ethnography, and scenarios) strengthen people's understanding of each of the trends.

In terms of the relationship of each trend within the DP/PLC/ICC scheme, Figure 9.2 locates each trend analyzed on the axis of the project, identifying the principal points at which each trend can be involved.

Beyond the focuses and differences of each trend, all of them share a common thread, namely, the welfare of the human being and the change from techno-centric design to an anthropocentric design. The different and sometimes opposing positions among trends are thus useful for complementing our understanding of the complex human nature and empowering product design.

Finally, although a wide variety of focuses, methods, tools, and applications, as well as differentiated purposes, can be distinguished in practice, in theoretical terms there is no clarity on ontological and epistemological aspects.

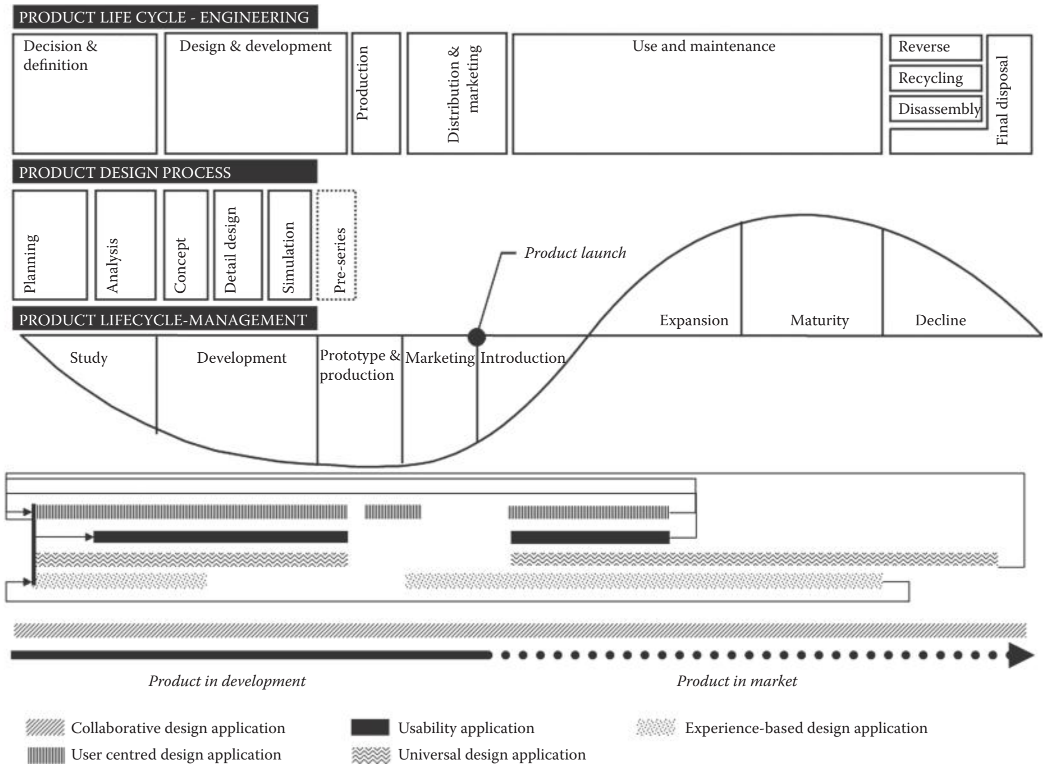


FIGURE 9.2 Location of anthropocentric design trends on the project axis in the PLC/DP/ICC scheme.

REFERENCES

Ames, A.L. 2001. Users first! An introduction to usability and user-centered design and development for technical information and products. IPCC 2001: IEEE International Professional Communication Conference, Proceedings – Communication Dimensions; IEEE International Professional Conference, Santa Fe, NM.

Andrew, J.P., and Dalens, F. 2004. Innovation to cash: Orchestrating in the consumer industry. Boston Consulting Group, Inc. http://www.bcg.com/documents/file14296.pdf (accessed January 20, 2010).

Aoyama, M. 2005. Persona-and-scenario based requirements engineering for software embedded in digital consumer products. In *Proceedings of the 13th IEEE International Conference on Requirements Engineering*, IEEE Computer Society, 85–94. Institute of Electrical and Electronics Engineers, Inc.

Babbar, S., Behara, R., and White, E. 2002. Mapping product usability. *International Journal of Operations & Production Management* 22 (9–10): 1071–89.

Bate, P., and Robert, G. 2006. Experience-based design: From redesigning the system around the patient to co-designing services with the patient. *Quality & Safety in Health Care* 15 (5): 307–10.

Bennett, J.L. 1979. The commercial impact of usability in interactive systems. *Man-Computer Communication, Infotech State-of-the-Art* 2:1–17.

Bjelland, H.V., and Tangeland, K. 2007. User-centered design proposals for prototyping haptic user interfaces. Paper presented at Haptic and Audio Interaction Design, Proceedings; Lecture Notes in Computer Science; 2nd International Workshop on Haptic and Audio Interaction Design, Seoul, South Korea.

Bjork, E., and Ottosson, S. 2007. Aspects of consideration in product development research. *Journal of Engineering Design* 18 (3): 195–207.

Blomberg, J., Giacomi, J., Mosher, A., and Swenton-Wall, P. 1993. Ethnographic field methods and their relation to design. In *Participatory Design: Principles and Practices*, eds. D. Schuler and A. Namioka, 123–55. Hillsdale, NJ: Erlbaum Associates.

Bonapace, L. 1999. The ergonomics of pleasure. In *Human Factors in Product Design: Current Practice and Future Trends*, eds. W.S. Green and P.W. Jordan, 234–48. London: Taylor & Francis.

Brown, J.S., and Newman, S.E. 1985. Issues in cognitive and social ergonomics: From our house to bauhaus. *Human-Computer Interaction* 1 (4): 359–91.

Chamorro-Koc, M., Popovic, V., and Emmison, M. 2009. Human experience and product usability: Principles to assist the design of user-product interactions. *Applied Ergonomics* 40 (4): 648–56.

Clarkson, P.J., Keates, S., Coleman, R., Lebbon, C., and Johnston, M. 2000. A model for inclusive design. In *Engineering Design Conference 2000: Design for Excellence*, eds. S. Sivaloganathan and P.T. Andrews, 203–12. Trowbridge, Wiltshire: Professional Engineering Publishing Limited.

Connell, B.R., Jones, M., Mace, R., Mueller, J., Mullick, A., Ostroff, E., Sanford, J., Steinfeld, E., Story, M., and Vanderheiden, G. 1997. The principles of universal design. http://www.design.ncsu.edu/cud/newweb/about_ud/udprinciples.htm (accessed December 20, 2005).

Crews, D.E., and Zavotka, S. 2006. Aging, disability, and frailty: Implications for universal design. *Journal of Physiology and Anthropology* 25 (1): 113–18.

Cross, N. 2003. *Métodos de diseño*. Madrid: Alfaomega.

Damodaran, L. 1983. User involvement in system design. *Data Processing* 25 (6): 6–13.

Dorfles, G., Mora, J.M., and Cirici, A. 1968. *El diseño industrial y su estética*. Barcelona: Labor.

Eason, K.D. 1995. User-centered design – for users or by users. *Ergonomics* 38 (8): 1667–73.

Eng, N.L., Bracewell, R.H., Clarkson, P.J., Giess, M.D., McMahon, C.A., Conway, A.P., and Ion, W.J. 2008. Comparing and integrating methods of design activity documentation across synchronous and asynchronous modes of collaborative work. In *Proceedings of Norddesign 2008*, ed. L. Roosimölder, 243–52. Design Society and Tallinn University of Technology.

Fanucci, L., Giusti, D., Roncella, R., Scebba, A., and Vaccari, G. 2007. Helpiphone: A successful case of technology transfer. *Challenges for Assistive Technology* 20:715–19.

Fathianathan, M., and Panchal, J.H. 2009. Incorporating design outsourcing decisions within the design of collaborative design processes. *Computers in Industry* 60 (6): 392–402.

Frandsen-Thorlacius, O., Hornbaek, K., Hertzum, M., and Clemmensen, T. 2009. Non-universal usability? A survey of how usability is understood by Chinese and Danish users. Paper presented at Chi2009: Proceedings of the 27th Annual Chi Conference on Human Factors in Computing Systems, Vols 1–4; 27th Annual CHI Conference on Human Factors in Computing Systems, Boston, MA.

Fulton Suri, J. 2007. Involving people in the process. Keynote presented at Include Conference 2007, Helen Hamlyn Research Institute, Royal College of Art, London.

Fulton Suri, J., and Marsh, M. 2000. Scenario building as an ergonomics method in consumer product design. *Applied Ergonomics* 31 (2): 151–57.

García Acosta, G. 2009. Reconocimiento inicial: Enfoques de documentos (casos, métodos/técnicas y conceptos) relacionados con el diseño para seres humanos/usuarios/clientes/consumidores/colaboradores. Universitat Politecnica de Catalunya, Barcelona.

García Acosta, G., Lange Morales, K., Ruiz Ortiz, M.R., Puentes Lagos, D.E., and Parada Parada, S.E. 2009. Electronic device design for brackets positioning by direct method. Paper presented at 17th World Congress on Ergonomics Conference Proceedings. International Ergonomics Association, Beijing.

Gardner, H. 1999. *Intelligence Reframed: Multiple Intelligences for the 21st Century*. New York: Basic Books.

Geertz, C., and Clifford, J. 1991. *El surgimiento de la antropología posmoderna*. México: Gedisa.

George, C.A. 2008. Lessons learned: Usability testing a federated search product. *Electronic Library* 26 (1): 5–20.

Goel, V. and Pirolli, P. 1992. The structure of design problem spaces. *Cognitive Science* 16:395–429.

Goldin, D.S., Venneri, S.L., and Noor, A.K. 1999. New frontiers in design synthesis. *Acta Astronautica* 44 (7–12): 407–18.

Goleman, D. 1995. *Emotional Intelligence*. New York: Bantam Books.

Greene, S.L., Jones, L., Matchen, P., and Thomas, J.C. 2003. Iterative development in the field. *IBM Systems Journal* 42 (4): 594–612.

Guba, E.G., and Lincoln, Y.S. 2005. Paradigmatic controversies, contradictions, and emerging confluences. In *The Sage Handbook of Qualitative Research*, eds. N.K. Denzin and Y.S. Lincoln, 3rd ed, 191–215. Thousand Oaks, CA: Sage.

Ha, T., Chang, Y., and Woo, W. 2007. Usability test of immersion for augmented reality based product design. In *Technologies for E-Learning and Digital Entertainment*, eds. K-c. Hui, Z. Pan, R.C-k. Chung, C.C.L. Wang, X. Jin, S. Göbel, and E.C.L. Li, 152–61. Berlin: Springer-Verlag.

Helms, J.W., Arthur, J.D., Hix, D., and Hartson, H.R. 2006. A field study of the wheel – a usability engineering process model. *Journal of Systems and Software* 79 (6): 841–58.

Hirata, I., and Yamaoka, T. 2007. A method of design improvement with the structured product concept. Paper presented at Universal Access in Human Computer Interaction: Coping with Diversity, Pt 1; Lecture Notes in Computer Science; 4th International Conference on Universal Access in Human-Computer Interaction held at the HCI International 2007, Beijing, China.

Hou, J.M., Su, C., and Wang, W.S. 2008. Knowledge management in collaborative design. *IEEE/SOLI'2008: Proceedings of 2008 IEEE International Conference on Service Operations and Logistics, and Informatics*, Vols. 1 and 2, IEEE Service Operations and Logistics, and Informatics (SOLI), 848–52. IEEE Press.

Jeong, S-H. 2007. Suggestion of methods for understanding user's emotional changes while using a product. Paper presented at Human Interface and the Management of Information: Methods, Techniques and Tools in Information Design, Pt 1, Proceedings; Lecture Notes in Computer Science; Symposium on Human Interface held at the HCI International 2007, Beijing, China.

Jimenez Narváez, L.M. 2000. Design's own knowledge. *Design Issues* 16 (1): 36–51.

Jokela, T., Siponen, M., Hirasawa, N. and Earthy, J. 2006. A survey of usability capability maturity models: Implications for practice and research. *Behaviour & Information Technology* 25 (3): 263–82.

Jordan, P.W. 1994. What is usability? In *Contemporary Ergonomics 1994*, ed. S.A. Robertson, 516–20. London: Taylor & Francis.

———. 2000. *Designing Pleasurable Products: An Introduction to the New Human Factors.* London: Taylor & Francis.

Kamper, R.J. 2002. Extending the usability of heuristics for design and evaluation: Lead, follow get out of the way. *International Journal of Human-Computer Interaction* 14 (3–4): 447–62.

Karapanos, E., and Martens, J.-B. 2007. Characterizing the diversity in users' perceptions. Paper presented at Human-Computer Interaction – INTERACT 2007, Pt 1, Proceedings; Lecture Notes in Computer Science; 11th IFIP International Conference on Human-Computer Interaction, Rio de Janeiro, Brazil.

Kaygan, H. 2008. Marketable emotions or engaging experiences: Towards a conquest of emotionality in design. *Metu Journal of the Faculty of Architecture* 25 (1): 177–90.

Ketola, P. 2000. Usability engineering in concurrent product development. Paper presented at Product Focused Software Process Improvement; Lecture Notes in Computer Science; 2nd International Conference on Product Focused Software Process Improvement (PROFES 2000), Oulu, Finland.

Khalid, H.M. 2006. Embracing diversity in user needs for affective design. *Applied Ergonomics* 37 (4): 409–18.

Khalid, H.M., and Helander, M.G. 2006. Customer emotional needs in product design. *Concurrent Engineering-Research and Applications* 14 (3): 197–206.

Kleinginna, P.R., and Kleinginna, A.M. 1981. A categorized list of emotion definitions, with suggestions for a consensual definition. *Motivation and Emotion* 5 (4): 345–79.

Kobayashi, T., Miyamoto, H., and Komatsu, M. 2009. Human-centered design approach for middleware. *Fujitsu Scientific & Technical Journal* 45 (2): 195–201.

Krippendorff, K. 2007. The cybernetics of design and the design of cybernetics. *Kybernetes* 36 (9–10): 1381–92.

Kroes, P. 2001. Technical functions as dispositions: A critical assessment. *Techné (Electronic Journal of the Society for Philosophy and Technology)* 5 (3): 1–16.

Kujala, S. 2003. User involvement: A review of the benefits and challenges. *Behaviour & Information Technology* 22 (1): 1–16.

Kujala, S., and Mantyla, M. 2000. How effective are user studies? Paper presented at People and Computers XIV – Usability Or Else!; BCS Conference Series; Annual Conference on Human-Computer Interaction Topics (HCI 2000), Sunderland, UK.

Kwon, B.Y., Park, L.W., Kang, Y.U., and Kweon, O.S. 1999. Human, activity, product, and observation method for user centered product design. *Advances in Occupational Ergonomics and Safety* 3:29–34.

Lange Morales, K. 1997. ¿Hacia el diseño de objetos más humanos? Productos únicos fabricados en serie. Tesis. Universidad Rafael Landívar, Guatemala.

Lange Morales, K., and Becerra Sáenz, R. 2007. Teaching Universal Design in Colombia: The Academic Approach of Two Universities. In *Include 2007 Proceedings*. Royal College of Art – Helen Hamlyn Centre. http://www.ektakta.com/include/files2/1_84.pdf (accessed October 25, 2009).

Lazar, J. 2007. *Universal Usability: Designing Computer Interfaces for Diverse User Populations.* Chichester: John Wiley.

Leuner, B. 1966. Emotional intelligence and emancipation. *Praxis Der Kinderpsychologie Und Kinderpsychiatrie* 15:193–203.

Lin, C.C., and Luh, D.B. 2009. A vision-oriented approach for innovative product design. *Advanced Engineering Informatics* 23 (2): 191–200.

Liukkunen, K., Etelapera, M., Oivo, M., Soininen, J.-P. and Pellikka, M. 2008. Virtual prototypes in developing mobile software applications and devices. Paper presented at Product-Focused Software Process Improvement, Proceedings; Lecture Notes in Computer Science; 9th International Conference on Product-Focused Software Process Improvement, Frascati, Italy.

March, A. 1994. Usability – the new dimension of product design. *Harvard Business Review* 72 (5): 144–49.

Margolin, V. 1997. Getting to know the user. *Design Studies* 18 (3): 227–36.

Marincek, C. 2007. Design for all in information society. *Proceedings of the 9th Congress of the European Federation for Research in Rehabilitation*, 19–24. Medimond - Monduzzi Editore International Proceedings Division.

Marshall, R., Case, K., Porter, M., Summerskill, S., Gyi, D., Davis, P., and Sims, R. 2010. HADRIAN: A virtual approach to design for all. *Journal of Engineering Design* 21 (2): 253–73.

Miller, R.B. 1971. Human ease of use criteria and their tradeoffs. *IBM Technical Report TR 00.2185*. Poughkeepsie, NY: IBM Corporation.

Nagamachi, M. 2002. Kansei engineering as a powerful consumer-oriented technology for product development. *Applied Ergonomics* 33 (3): 289–94.

Nielsen, J. 1993. *Usability Engineering.* San Diego, CA: Academic Press.

Nieters, J., and Williams, D. 2007. Collaborative design for strategic UXD impact and global product value. Paper presented at Human-Computer Interaction, Pt 1, Proceedings - Interaction Design and Usability; Lecture Notes in Computer Science; 12th International Conference on Human-Computer Interaction (HCI International 2007), Beijing, China.

Norman, D.A. 1988. *The Psychology of Everyday Things.* New York: Basic Books.

———. 2004. *Emotional Design: Why We Love (or Hate) Everyday Things.* New York: Basic Civitas Books.

Norman, D.A., and Draper, S.W. 1986. *User Centered System Design; New Perspectives on Human-Computer Interaction*. Hillsdale, NJ: Erlbaum Associates.

Noro, K., and Imada, A.S. 1991. *Participatory Ergonomics.* Philadelphia: Taylor & Francis.

Ostergaard, K.J., and Summers, J.D. 2009. Development of a systematic classification and taxonomy of collaborative design activities. *Journal of Engineering Design* 20 (1): 57–81.

Ostroff, E. 2001. Universal design: The new paradigm. In *Universal Design Handbook*, eds. W.F.E. Preiser and E. Ostroff, 1.3–1.12. New York: McGraw-Hill.

Paul, C.L. 2009. A survey of usability practices in Free/Libre/Open source software. *Open Source Ecosystems-Diverse Communities Interacting* 299:264–73.

Payne, W.L. 1985. A study of emotion: Developing emotional intelligence; self-integration; relating to fear, pain and desire (theory, structure of reality, problem-solving, contraction/expansion, tuning in/coming out/letting go). PhD Dissertation. The Union for Experimenting Colleges and Universities (Now the Union Institute), Cincinnati, OH.

Pejtersen, A.M. 1984. Design of a computer-aided user-system dialogue based on an analysis of users' search behaviour. *Social Science Information Studies* 4 (2–3): 167–83.

Porter, J.M., Case, K., Marshall, R., Gyi, D., and Oliver, R.S.N. 2004. 'Beyond jack and jill': Designing for individuals using HADRIAN. *International Journal of Industrial Ergonomics* 33 (3): 249–64.

Puentes Lagos, D.E. 2009. Tecnología y prospectiva en el trabajo. Paper presented at 7 Congreso Internacional Crisis Global, Salud y Trabajo, Universidad Nacional de Colombia, Bogotá.

Pullin, G. 2007. When fashion meets discretion. In *Include 2007 Proceedings*. Royal College of Art – Helen Hamlyn Centre. http://www.ektakta.com/include/files2/1_50.pdf (accessed October 20, 2009).

Riba Romeva, C.R. 2002. *Diseño concurrente.* Barcelona: Edicions UPC.

Rompay, T., Hekkert, P., Saakes, D., and Russo, B. 2005. Grounding abstract object characteristics in embodied interactions. *Acta Psychologica* 119 (3): 315–51.

Salovaara, A., and Mannonen, P. 2005. Use of future-oriented information in user-centered product concept ideation. In *Human-Computer Interaction - Interact 2005*, eds. M.F. Costabile and F. Paternò, Volume 3585, pp. 727–40. Berlin: Springer.

Salovey, P., and Mayer, J.D. 1990. Emotional intelligence. *Imagination, Cognition and Personality* 9 (3): 185–211.

Schutte, S.T.W., Eklund, J., Axelsson, J.R.C., and Nagamachi, M. 2004. Concepts, methods and tools in Kansei engineering. *Theoretical Issues in Ergonomics Science* 5 (3): 214–31.

Shackel, B. 1986. Ergonomics in design for usability. In People and computers: Designing for usability, Proceedings of the Second Conference of the BCS HCI specialist group, eds. M.D. Harrison and A.F. Monk, 23–26, 44–64. Cambridge: Cambridge University Press.

Shen, W.M., Hao, Q., and Li, W.D. 2008. Computer supported collaborative design: Retrospective and perspective. *Computers in Industry* 59 (9): 855–62.

Sivakumar, K., and Nakata, C. 2003. Designing global new product teams – optimizing the effects of national culture on new product development. *International Marketing Review* 20 (4): 397–445.

Skelton, T.M., and Thamhain, H.J. 2005. User-centered design as a risk management tool in new technology product development. Paper presented at 2005 IEEE International Engineering Management Conference, Vols. 1 and 2; IEEE International Engineering Management Conference, St Johns, Canada.

Stuart, M., and Weinrich, M. 2001. Home- and community-based long-term care: Lessons from Denmark. *Gerontologist* 41 (4): 474–80.

van Tooren, M., and La Rocca, G. 2008. Systems engineering and multi-disciplinary design optimization. Paper presented at Collaborative Productive and Service Life Cycle Management for a Sustainable World; 15th International Conference on Concurrent Engineering, Belfast, North Ireland.

Vogel, C.M. 2008. The live well collaborative: A new model for universities and companies to work together to meet the needs of 50+ consumers. *Topics in Stroke Rehabilitation* 15 (2): 103–8.

Yamazaki, K., and Furuta, K. 2007. Design tools for user experience design. In Human-Computer Interaction, Interaction Design and Usability 12th International Conference, HCI International 2007, Pt 1, ed. J.A. Jacko, Volume 4550, 298–307. Berlin: Springer.

Yu, J.W., and Jing, R.Z. 2008. On cooperative innovation system of production, teaching and research based on industry clusters. *Proceeding of the Seventh International Conference on Information and Management Sciences* 7:81–86.

10 Integration of Ergonomics in the Design Process: Conceptual, Methodological, and Practical Foundations

Luz Mercedes Sáenz Zapata

CONTENTS

10.1 INTRODUCTION

The scientific discipline of ergonomics has become increasingly important not only in the workplace but also in the realms of academia, science, and the day-to-day lives of individuals. Its anthropocentric perspectives and approach has led to the development of a theoretical and practical framework in which a fundamental goal is the optimization of human well-being—initially in the workplace, but increasingly so in other domains of human life.

Moreover, design—as a creative and anthropocentric-focused discipline—has experienced a methodological resurgence and can now be understood as a plan, process, or project to shape, validate, and market anything from products, pictures, clothes, spaces, and environments; the objective being to satisfy the needs of a diverse range of users in such varied environments as the workplace, recreational settings, at home, and in the community (Sáenz and Sevilla 2007).

Ergonomics and design utilize subject-content, methodologies, and various techniques and tools to analyze and evaluate day-to-day situations, which in turn allows a clear conceptualization of the "user-product-context" relationship. These day-to-day situations form the basis for a research process comprising observation, documentation, analysis, annotation, summaries, and conclusions. The whole process is geared toward the creation of products based on the requirements and characteristics of its prospective users and the environment in which those products are to be used.

Both disciplines have evolved, particularly in their understanding of how relationships are established between people and the objects that are required to carry out day-to-day activities. In addition to analyzing the nature of certain situations, carrying out diagnostics and offering solutions for the working environment, ergonomics now expands into diverse realms of human activity. Similarly, design is not only concerned nowadays with appearance and the aesthetic nature of products; it also recognizes the importance of the relationship between the product and the user and its impact on the latter in terms of comprehension, effectiveness, well-being, and safety. Thus, having found common ground, advances in ergonomics and design have led to the articulation of subjects and procedures whose objective—from the stage of conception—is to create objects/products that will facilitate daily lives, develop awareness, and improve the well-being and security of the users.

10.2 ERGONOMICS AND DESIGN INTEGRATION: CONCEPTUAL AND THEMATIC FEATURES

Ergonomics and design emerged at different times and in different circumstances; nonetheless, both disciplines embrace a very similar objective: people's well-being, health, and safety. Both share the same visions, and in thematic terms complement each other in their pursuit of procedures and products that make human activity easier, more effective, and more efficient.

For the purposes of this chapter, the following definition should be considered when referring to the term "design":

> The Object-Design Process and the requisite factors that need to be taken into consideration in the creation of industrial products, required by an individual to carry out day-to-day functions be it work-related, recreational, domestic, public, or in any other context, and which fosters the development of material culture thus promoting wellbeing and quality of life. (Sáenz 2008, 174)

This theory establishes the relationship between ergonomics and design through the following factors:

- Shared anthropocentric, systematic, and interdisciplinary perspectives
- A complementary contribution in the configuration process that combines a human approach (ergonomics) and an object approach (design)
- A capitalization of common criteria relating to the functional-operational nature of the object

10.2.1 Anthropocentric, Systematic, and Interdisciplinary Perspectives

The theory of ergonomics—derived from the Greek word *ergon* [work] and *nomos* [natural law]—was originally conceived and proposed by the Polish scientist B.W. Jastrzebowski as the "science of work." Its aim was to ameliorate conditions and safety in the workplace (Karwowski 2006). Since its emergence, this conception of ergonomics has been geared toward optimizing the person-machine-environment system comprising three fundamental variables that give relevance to the human component and the relationships that are established therein (De Montmollin 2000).

Anthropocentric and systematic perspectives are therefore established in order to analyze each of these three variables and specify a product's requirements based on an individual's characteristics and the context in which the product will be used. Thereafter, the methodology of ergonomics can be used to observe, analyze, and interpret the product requirements to create diagnostics and applications, which will be used to create conditions of health and safety in various contexts (Sáenz 2008).

The process of giving form and structure to products that are required for people's day-to-day lives demands analysis, diagnosis, and implementation. It should include the following variables present in the relationship of use: user, product, and context (Sáenz 2005). The components of this system, commonly referred to in ergonomic as person-machine-environment, constitute the elements common to both systems.

An interdisciplinary perspective is also common in ergonomics and design. Diverse areas of knowledge must be incorporated into the process in order to understand an activity or situation of use, guarantee a satisfactory analysis, and ensure access to specific criteria for the final recommendations/conclusions that determine the operational quality (Vidal 2002) of the methods of use, the objects required, and the context or environment related to the activity.

10.2.2 Ergonomics and Design: A Human Perspective and the Perspective of the Object

In thematic terms, ergonomics and design interact by striving toward a common goal: optimizing the conditions of the user while at the same time considering the objects that are required to carry out day-to-day activities in any given context.

Ergonomics presents us with a human perspective based on scientific knowledge, which enables the characterization and understanding of certain physical dimensions: physiological, anthropometric, and biomechanical (Konz 2006), expressed as physical domains according to the International Ergonomics Association (IEA Council 2000); and cognitive dimensions: mental processes, perception, memory, reasoning and motor response, and how they shape the interaction between humans and other elements in the system. These are expressed as dominions of cognitive ergonomics (IEA Council 2000). User elements—a human perspective—can be seen in Figure 10.1.

The IEA also comprises an organizational domain that takes into account the structure, policies, and management of labor, thereby incorporating such areas as design, new patterns of occupational activity, teamwork, participative design, and management expertise (IEA Council 2000).

The term "design" has been used to describe any creative activity that attempts to improve on an existing idea or present an original alternative, and has been extended to various fields of knowledge. As such, it is possible to design—among other things—plans, strategies, projects, consumer products for everyday life, and space (Sáenz 2008). Nowadays, design can also be regarded as an experience; a process that generates meaningful changes to people's lives (Press and Cooper 2009).

For the purposes of this chapter, design is seen as "a creative activity which goes beyond determining the formal of industrially produced objects" (Maldonado 1977, cited in Maldonado 1961). Therefore, design determines a product's physical attributes: its form (geometric pattern, perimeters, structure, size, symmetry, texture, and color) and material (density, friction, mechanical attributes: stress and distortion, and thermal attributes: temperature and electrical attributes) that are consistent with the characteristics and needs of the user and the characteristics and functional requirements of the products, which, in turn are determined by the features and specific criteria in which the activity takes place (see Figure 10.1).

In addition, these physical attributes also determine a product's use-value, defined as the suitability of form that is required to carry out a function in an efficacious manner (Fornari 1989). They also convey the conditions that will aid the adaptation of objects/machines to the psycho-physical features of the user, making it user-friendly, and adjusting the object/machine's characteristics to fit a user's capabilities and/or physical limitations and perceptions (Sáenz 2005).

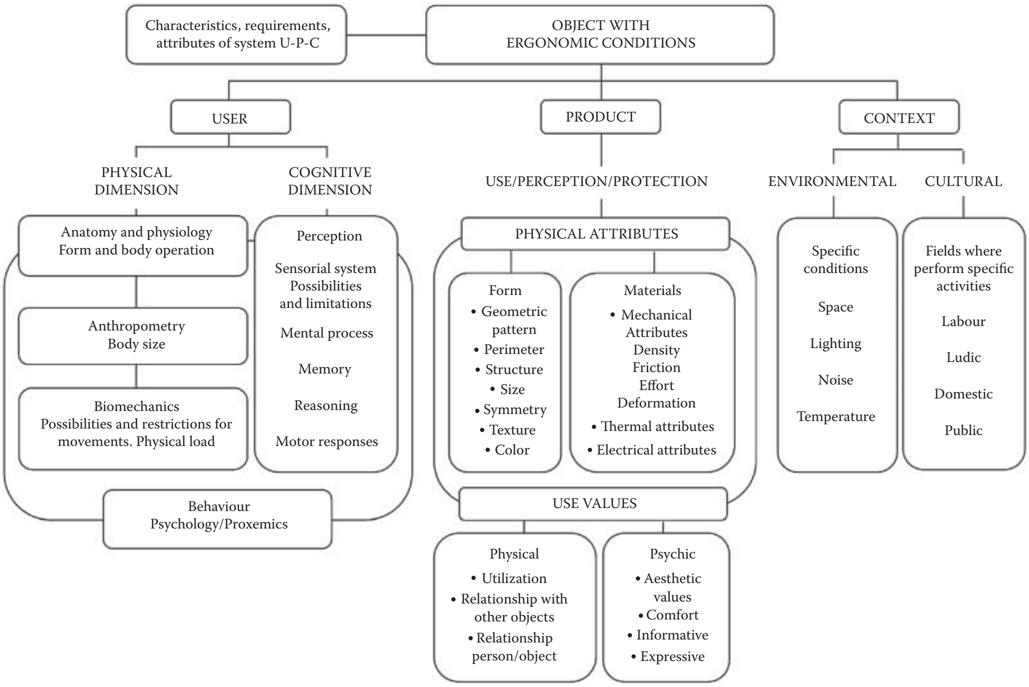


FIGURE 10.1 Reference elements from the ergonomics as a system.

In the relationship between ergonomics and design, the human and object perspectives determine the appropriate conditions between the user and the product, taking into account the environment in which these conditions will exist. In effect, this constitutes an object with ergonomic conditions (the relationships of the variables that comprise the user-product-context also have to be considered here). Figure 10.2 shows a diagrammatic summary of the use-values of products.

10.2.3 Function of Objects in the Ergonomics and Design Relationship

Design enables people to meet their everyday needs and improve their quality of life (Max Neef et al. 1986). In order for this to happen, design must take into consideration the features that allow a product to fully develop the function for which it was originally conceived.

The technical dimensions of a product determine if the function is physically viable. However, it is also imperative that the criteria of its use and its adaptability to humans are conceived in such a way as to take into consideration such things as the variability of the human form (physically, cognitively, and mentally: anthropometric characteristics, gender, age, culture, ability to assimilate information, etc.), the period of usage, environmental conditions, the number of simultaneous users, perceptive aspects, and if the user interface requires simultaneous interaction with other objects.

Function is a product's axis of configuration that determines the technical and operational efficiency and its usefulness, as well as the relationship between the product and user in both physical and perceptive terms (Sáenz 2005).

As part of its disciplinary and pedagogical program of study, the Faculty of Industrial Design at the Universidad Pontificia Bolivariana (UPB) includes a body of knowledge known as "components," which help to expand a designer's education and understanding (Facultad de Diseño Industrial, Escuela de Arquitectura y Diseño UPB 2009). One of these is the functional-operational component, which presents an object in terms of its "usefulness." Influenced by context or activities, this defines the use-value of the object and its relationship with the user.

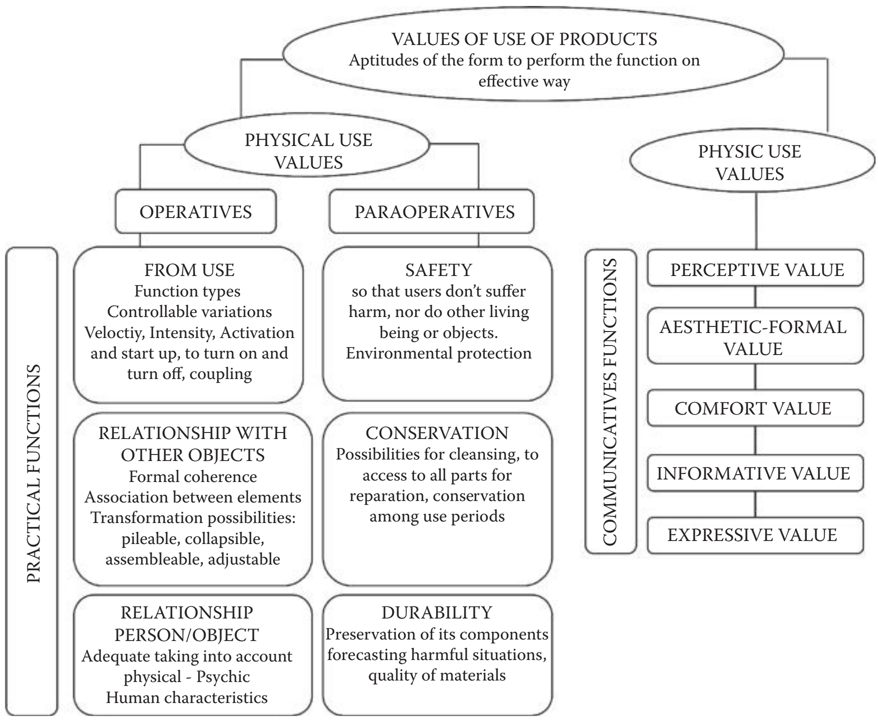


FIGURE 10.2 The use-values of products.

The functional-operational component is based on the relationship of the actions that develop by an object's form and materials so as to conform to an operator's requirements with the objective of modifying the physical world and producing an effect or a result into the operated product (Facultad de Diseño Industrial, Escuela de Arquitectura y Diseño UPB 2009). These aspects are consistent with the discipline of ergonomics, which considers a human being (the operator) carrying out an action in relation to the objects (machines/elements) that are required for everyday actions in different environments (the physical world) that include not just work-related activities, but also leisure time and reasoning (Karwowski 2006).

The functional-operational component provides a theoretical, practical, and methodological foundation for determining an object's form and functional properties (technical function), the service it provides (utility function), and the set of physical and cognitive actions that must be considered for the adaptation from object to the user (person-object relationship function) (Valencia 2007).

The person-object relationship function allows detailed analysis of a situation of use from the human perspective (ergonomics) and the object perspective (design). This is done by including dimensions in the configuration process of industrial objects that describe physical, social, and cognitive adaptation as well as user characteristics and requirements, and technical features relating to form and materials that affect the product's usefulness in any given environment (Sáenz 2005) (see Figure 10.3).

10.3 ERGONOMICS AND DESIGN INTEGRATION: A METHODOLOGICAL CONCEPT

Ergonomics and design can be regarded as intervention/application disciplines; both use systematic procedures that include observation, analysis, diagnosis, and presentation of proposals that materialize into products, procedures, and environments. They also establish a methodological relationship, complementing each other through their common interests, objectives, and procedures.

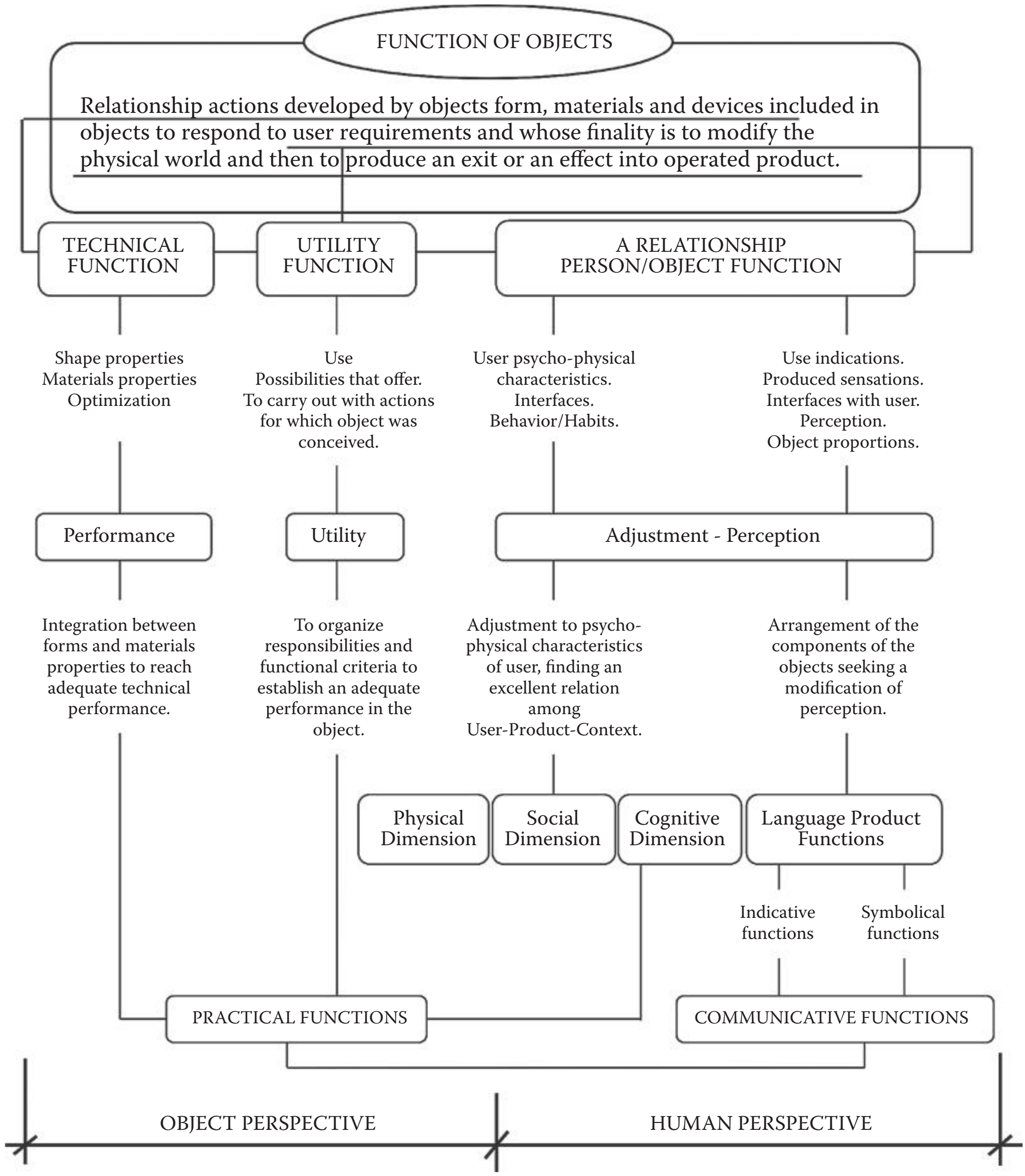


FIGURE 10.3 Objects and their functions.

Both disciplines provide elements that are required for the understanding and application of criteria that support the user-product-context relationship. In addition, both disciplines present different moments/activities that structure the design process in such a way that human factors/ergonomic criteria are taken into consideration from the initial stages of the process (Sáenz 2005).

The Faculty of Design at the UPB deems it important that the design process develops in a parallel and complimentary manner with the principles of ergonomics. A logical framework of procedures (Cross 2002) is introduced that integrates both disciplines and arranges the process in such a way so as not to exclude factors relevant to the project.

When the elements of ergonomics and design are integrated, it is also considered important to include a detailed account of the characteristics, capacities, and limitations of the user, the product's

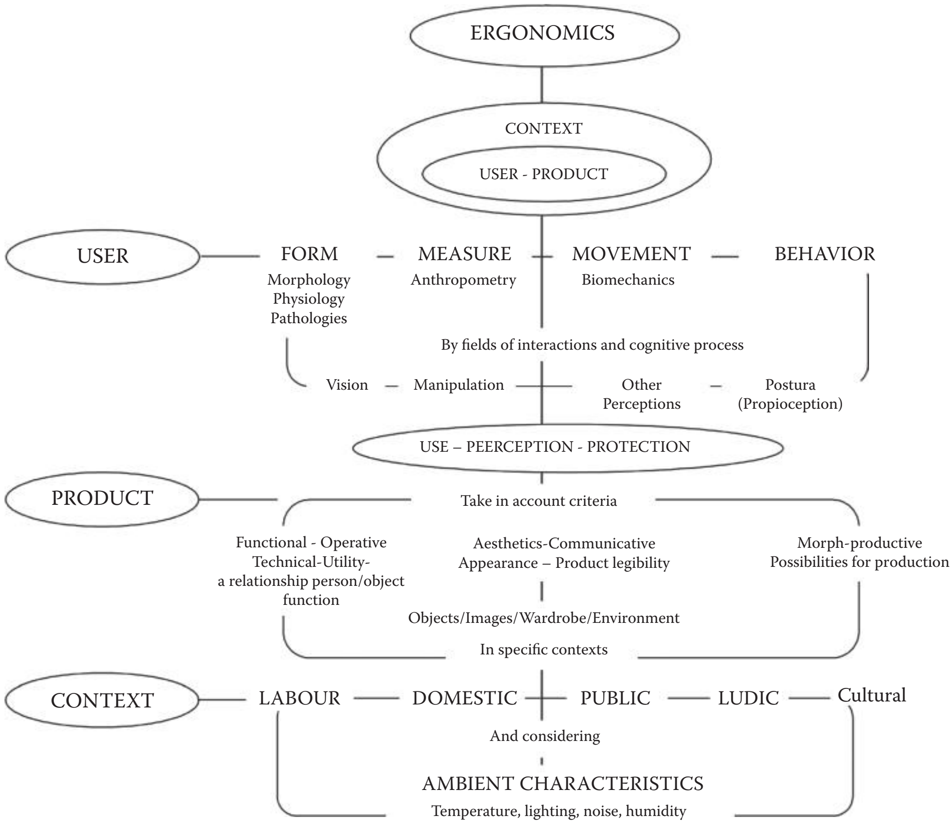


FIGURE 10.4 Subject units from the conceptual proposal presented by the Ergonomics Research Division of the GED from UPB.

requirements, and the conditions—both environmental and social—that relate to the context in which it is being used, and may influence the use and acceptation of the designed product.

The concept is also an excellent support tool for teaching and research (see Section 10.3.1) and has been proposed as a conceptual and methodological foundation for the Ergonomics Research Division of the Design Studies Group at the UPB (Sáenz 2006). This is in accordance with the Faculty of Design's disciplinary model at the UPB, which forms the basis for the education of industrial designers (Facultad de Diseño Industrial, Escuela de Arquitectura y Diseño UPB 2009).

10.3.1 Conceptual and Methodological Foundations of the Ergonomics Research Division of the Design Studies Group at the Universidad Pontificia Bolivariana

According to the Ergonomics Division of the Design Studies Group at the UPB, several thematic units, subjects, elements, and components should be considered throughout a product's design process. They are based on the user-product-context system (see Figure 10.4) and develop moments/activities that allow designers to use the process in a way that is systematic and coherent to the perspectives and approach of ergonomics.

10.3.1.1 Thematic Units

10.3.1.1.1 The User

The user is the person who uses the products (the result of the design process), taking advantage of and/or questioning the objectives of the products. Through product use and the user's requirements (needs and aspirations), the user becomes the driving force behind a process in which new products are developed and existing ones are improved. The objectives of design aim to satisfy the needs of the user and/or optimize well-being according to psycho-physical characteristics and requirements while bearing in mind the following points (Sáenz 2006):

- Physical form: morphology and physiology; characteristics of form and function of the parts of the body that are related to the product(s) involved in the relationship of use and activity.
- Physical measurements: anthropometric considerations that relate to the situation of use.
- Movement: biomechanical features, possibilities, and limitations.
- Behavior: as an individual and as a social being (psychology, proxemics, etc.), habits, differing ways of using a product, etc.

Similarly, certain “fields of interaction” with the surrounding environment should be considered: vision (seeing), manipulation (touching), other human senses (hearing, taste, and smell), and cognitive processes related to the carrying out of activities and use of objects. These “fields” form a morphological and physiological foundation that allows a human being to recognize their physical/cognitive dimensions as an individual, in their relationship with other people and space (Sáenz 2005) (see Figure 10.4).

10.3.1.1.2 The Product

The product is the result of the design process. It must be adaptable to user requirements, comply with a series of conditions that ensure the product is in good working order, and function well in the environment in which it is used. It is a proposal that, through the design process, becomes a form. Products exist because they might be useful, or useable (Sáenz 2006) and/or they may elicit an emotional response from the users.

For this to happen, three basic functions are considered: use, perception, and protection; and the following criteria observed: form, material, communicative aspects, production, appropriation of users, alternatives available on the market, legislation, and regulations.

This allows the designer to recognize and expand an object’s requirements as well as comply with conditions that will favor a greater degree of adaptation for the user and the optimization of the product’s function (Sáenz 2005). The products’ aspects can be seen in Figure 10.4.

10.3.1.1.3 The Context

The context is the environment or space in which the user carries out an activity using the designed products. The context allows a visualization of criteria from a cultural point of view: as a user interacting with others while carrying out basic activities such as survival, work, rest, and leisure, in different contexts such as work/domestic/public/entertainment; and from an environmental point of view: the characteristics in terms of temperature, illumination, noise, humidity, etc. (Sáenz 2005) (see Figure 10.4).

10.3.1.2 Stages/Activities

The steps/activities that are put forward in this methodological proposal comprise a sequence that divides a situation into each of the components of the ergonomic system: the user, the product, and the context, and identifies thematic subjects and actions that must be taken into account throughout the design process (Sáenz 2008) (see Figure 10.5).

The first stage/activity is to *identify*. The key points here are the characteristics and conditions observed in the thematic units: user-product-context. A clear understanding of the user’s capabilities and limitations, psycho-physical requirements, cognitive features, behavior, and habits must be established. The physical, cognitive, and social dimensions are identified at this stage, as well as the characterization of the product and the context of its use (elements that

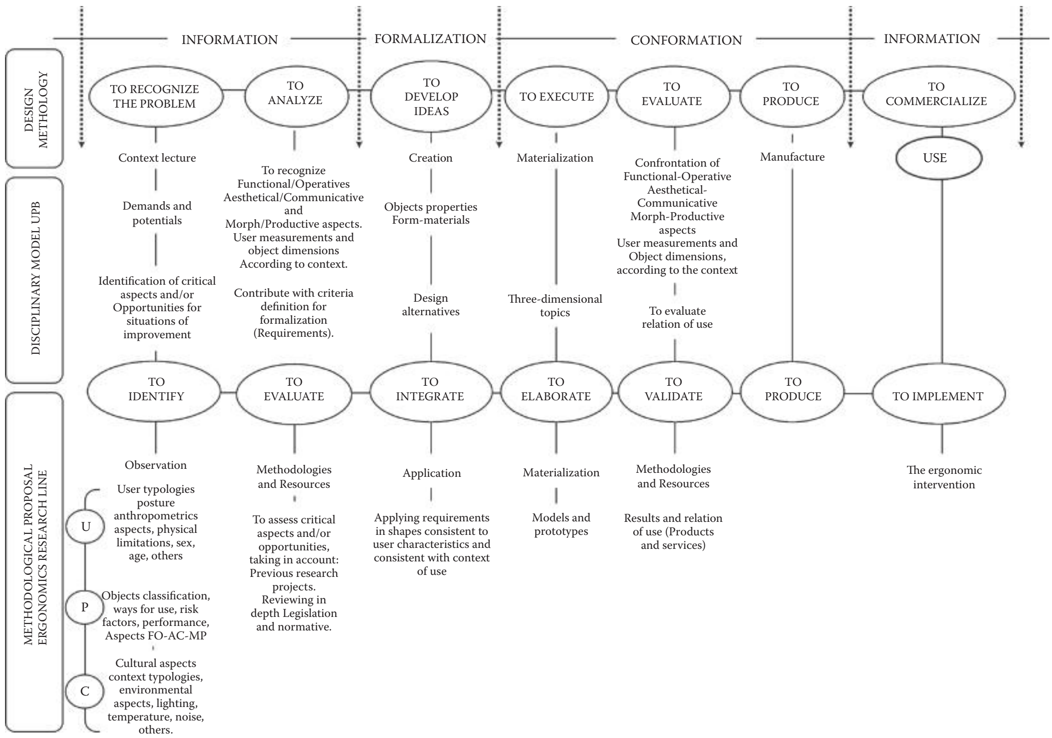


FIGURE 10.5 The design process and ergonomic intervention, parallel and complementary activities of the Ergonomics Research Division at the UPB, developed by Sáenz and Sevilla, September 2007.

define the degree to which a product fits the user as well as the conditions that promote welfare, health, and safety).

Once these characteristics have been recognized, the next step is to *assess* certain issues and opportunities that should take into account background research: current levels of innovation, conditions of use, current legislation and regulations, detailed observation using specific evaluation methods (methodological alternatives provided by ergonomics), and so forth. It is at the analysis stage that man confronts object and the functional-operational, aesthetic-communicational, and morphological-productive characteristics are observed. It is also the moment in which context is analyzed and the way that this might facilitate or hinder its use.

This stage should result in the discovery of a number of requirements that can be expressed in the form of concrete guidelines. It is the moment that brings to the fore the interdisciplinary approach of ergonomics since the information generated can be used by diverse fields of knowledge that come together and support the configuration process of the products/services and/or ergonomic intervention.

The next stage—by means of the methodological process—is to *integrate* (or apply) the requirements that were established in the first stages. The requirements are redesigned into "forms" that respond to a user's characteristics and are coherent to the context in which the product is to be used. It is the stage when formal proposals are conceived: theoretical/practical elements are observed and converted into tangible forms. Or, from an ergonomic point of view, make adjustments to the way in which a product is used (procedures) and/or the environment in which it is used.

The next stage sees the *elaboration* (or materialization) of ideas by creating models and prototypes that can be presented to the users. These ideas are transferred from paper to the three-dimensional domain, preferably on a human scale. It is the step of materializing and executing the ideas that were conceived in the first stage of analysis.

It is then necessary to *validate* the models and prototypes by testing them out with the users. This entails the application of methodologies and resources in order to establish product values, difficulties of use, special characteristics, etc., which will lead to either the product's endorsement or necessary adjustments for its improvements.

Validation is followed by the *production* stage—or manufacturing process—of the product and/or the execution of actions required to modify the procedure or environment. In the case of ergonomic intervention, it may be the case that the market already provides a viable solution that complies with all the necessary requirements discovered during the stages of analysis, in which case, design and production of a new product are not necessary.

Once the new product (or existing products that improve a user's conditions) is ready, and a series of actions/modifications that best complement a person's activity in order to improve the relationship of use have been carried out, the principles of ergonomics *implement* an intervention that—supported by the design process—has created a cycle in which a person performing an activity, the objects that are being used, and the surrounding environment are observed and efforts continue toward the optimization of well-being, health, and safety (see Figure 10.5).

10.3.2 Design Process in Accordance with the Disciplinary Model at the Faculty of Design at the Universidad Pontificia Bolivariana

Diverse models can be found that represent the sequence of activities that occur during the design process. These models describe in detail moments/activities that may not always occur in sequence; it may be necessary to return to an earlier stage to review a situation and its components in order to find a solution (Cross 2002).

The Faculty of Design at the UPB sees the design process as a procedure and a project. The different stages of the process establish important criteria for a designer's education from UPB by emphasizing the fundamental principles of investigation, theory, practice, and methodology. It also promotes a body of knowledge—known as components—that gives students of design a more comprehensive understanding of the subject (Facultad de Diseño Industrial, Escuela de Arquitectura y Diseño UPB 2009). The disciplinary model that is used at the Faculty of Design at the UPB includes a number of stages and moments, as shown in Figure 10.5.

Form does not exist in the first stage of the design process; it is simply a verbal concept. The moment is represented by information comprising data, social phenomena, and knowledge regarding psycho-physical, socio-cultural, and technical demands (requirements, characteristics, limitations, restrictions, criteria).

This first moment *recognizes the problem* based on a study of the context, understood here as the macro-environment in which the demands and potentials of the user can be observed. The ergonomic vision can recognize certain critical features and/or opportunities to improve a situation.

It is important to then *analyze* the product and its functional-operational, aesthetic-communicational, and morphological-productive elements that contribute toward the definition of criteria (requirements), which will be formalized at a later point.

These two initial moments constitute a phase that is characterized by the acquisition of INFORMATION (a result of the study and interpretation of the user's characteristics and requirements and the dynamics of context that help to establish design opportunities/problems) (Sanín 2005).

The next stage in the process is *idea development*. It is the stage of creation, the moment in which the configuration of form and the material properties of the product are devised. Different design proposals are presented that should take account of as many of the requirements obtained in the first stage as possible.

The development of ideas—or integration—is incorporated into a moment of FORMALIZATION, which comprises the translation of the verbal concept into a formal proposal. This process sees an object as a solution to the problem/opportunity identified at an earlier stage (Sanín 2005). It should be noted at this stage that the proposal is a representation and not an object that has been produced.

A moment of CONFORMATION sees the form—be it product or service—enter into the context. A materialization process generates a series of added values (commercial, institutional, cultural, etc.) to the product/service, allowing people to recognize a tangible solution to the original problem that may or may not have already been recognized by society. The moment of conformation comprises:

Realization and materialization of a three-dimensional representation of one or more alternatives. The representations must respond to the requirements established during the analysis of the user-product-context system. A subsequent stage of *assessment* sees the functional-operational, aesthetic, and communicational features confronted with a user's characteristics, prospects, and limitations.

Evaluation/validation provides new criteria that must be taken into account before final production of the object. The object's contact with the user is a definite indication of the condition of the user-product-context relationship. The validation process in design is similar to the process in ergonomics; both use a series of methods to quantitatively and qualitatively assess a person while they are performing an activity.

It is then possible to *produce* or manufacture the product, taking into consideration the conclusions obtained from potential users. The objective at this stage is to optimize available resources and ensure environmentally and socially sustainable production processes—in other words, the social equity that is produced for the benefit of producers and consumers alike.

In terms of design, a product is made readily available to use in everyday life through a process of *commercialization*. Commercial strategies are designed to generate an added value to a product by introducing it into the context. They are generally represented by objects, by means of its three dimensions (functional, aesthetic, and communicational), reflecting a set of distinguishing characteristics that define and sell the brand.

Ergonomic conditions can be considered valuable in the sense that they optimize the characteristics and components of the user-product-context system.

A synthesis is achieved between the perspectives and approach of the Ergonomics Research Division of the Design Studies Group at the UPB and the disciplinary model of the Faculty of Industrial Design at the UPB, as shown in Figure 10.5. The relationship is established because of the analogous and parallel way that they can be developed and, more pertinently, because they contribute to an interpretation of design that understands the needs and requirements of the user from the beginning of the process and not as isolated concepts.

10.4 ERGONOMICS AND DESIGN INTEGRATION: A PEDAGOGIC CONCEPT

In addition to conceiving the shared visions of ergonomics and design, the complementary nature of their thematic content and the analogous techniques that can be used in the configuration process of industrial objects, the Faculty of Industrial Design at the UPB uses the ergonomics-design relationship as the basis for a strategy of professional education, structured to complement the objectives that guide the university: teaching, research, and outreach (Universidad Pontificia Bolivariana 2004).

Hence, ergonomics and design integration is incorporated into theoretical-practical undergraduate and post-graduate courses, think-tanks, graduation projects (research education), and applied research projects. In addition, the university offers a consulting service for companies that wish to integrate the principles of ergonomics into their products, goods, and services.

Outlines of two projects that concomitantly identified the design process and ergonomic intervention are presented below. The first was a graduation project (research training that formed part of the Industrial Design undergraduate course); the second was a workshop exercise completed in the sixth semester (Design workshop). Both projects were concerned with the specific needs of vulnerable peoples (due to their psycho-physical characteristics and economic situations).

10.4.1 Recreational Objects to Support the Learning Process of Visually Impaired Children: Imaginary Friends

This first example formed part of a degree project program at the Faculty of Industrial Design. Its goal was to develop the students' research skills through active participation in one of the divisions in the research group of the GED (Design Studies Research Group): ergonomics, material culture, or experimental morphology, and then applying these skills in a design project.

These projects are developed in the following three stages (from the sixth to the ninth semester of the undergraduate course):

- Identification of a problem: Objectives are established and a theoretical framework is developed.
- Fact finding and fieldwork: The focus at this stage is on research training; students are encouraged to look at the evidence from different angles and perspectives—in this case the ergonomics-design relationship.
- Conceptualization and design: This stage integrates the research process with the disciplines of design. Knowledge acquired in the earlier stages is incorporated into the process of creating new design concepts that are applied in a proposal that methodologically underlines the principles and procedures of ergonomics and design.

Supported by the Ergonomics Research Division of the Design Studies Group at the UPB, the project "Recreational Objects to Support the Learning Process of Visually Impaired Children: Imaginary Friends" (Lotero and Henao 2009) had the following objectives:

- To identify the criteria for the ergonomics and design of a space or object that integrates recreation and learning in an environment conducive to the emotional, physical, and intellectual development of visually impaired children (reflecting the current push toward "design for all").
- To design a set of objects that fosters the stimulation necessary in the development of visually impaired children and provide them with recreational experiences that improve their quality of life and help them cope with their impairment.

BABEL is a recreational learning set of objects for visually impaired pre-school children (3–6 years old), which helps to promote their integration into society by teaching them the universal language of simple figures. In addition, it provides children who are not visually impaired with opportunities to learn this universal language used by people with visual impairment. The set of objects can be used simultaneously by several children. Figures 10.6 and 10.7 show the result of the Imaginary Friends project: BABEL (designed by Ana María Lotero, Mariana Henao, and Sebastián González).

A 60 degree inclination means that the children can play while sitting in a comfortable position. It has three degrees of difficulty separated into levels from the top to the lower part of the system. The first level includes: basic geometric figures, the numbers 1–10, and the primary colors in order of contrast, all written in Braille and the universally recognized alphabet. The second level (intermediate) includes the universal alphabet and figures that project out. In the third level (advanced), children can practice forming words and sentences using the aforementioned alphabet. The unit has a central axis of rotation and each level can be rotated to interact with each other. A storage container is also included so that the children can tidy away once they've finished using the object. From the outset, the principles of ergonomics and design were taken into account in an analogous manner (see Table 10.1).

FIGURE 10.6 BABEL: the relationship between user and product.

As an undergraduate project, the process evolved right up until the production stage (a final prototype with adjustments based on the results of user testing). The project has all the prerequisites for future commercial marketing.

10.4.2 Design for the Elderly: Application of Ergonomics in the Development of Technical Aids

This project was conceived by students in the design workshop in the sixth semester (Integral Product Nucleus) of the Faculty of Design at the UBP, with teaching support from the Ergonomics Research Division of the GED.

The objective of the project was to design technical aids for elderly people in two state-run nursing homes, which provide accommodation, food, recreational facilities, and medical and psychological preventative care on a permanent or temporary basis (Sevilla and González 2008).

The students were granted direct contact with the guests in the nursing homes, allowing them to ascertain the users' physical-functional and cognitive limitations. In addition, students interacted with the staff in order to envision design opportunities to benefit them as employees. As part of the project's directives, the students had to take into consideration the low financial resources available to the publically funded homes.

Proposals were drawn up by the students in the Faculty of Industrial Design at the UPB and developed according to the methodological conception of the faculty, and are currently being used in nursing homes for the elderly (see Table 10.2). The technical aids were developed right up until the production stage; one prototype is currently being used in each nursing home. Insufficient funds prevented the commercial marketing of the products.

FIGURE 10.7 BABEL: contact between the user and the object's Braille system.

10.4.2.1 ANPHIBIA—Furniture for Personal Hygiene Activities

Designed by Sandra Parra, Juan David Herrera, and Julián Vanegas, ANPHIBIA is a chair made of aluminium, glass fiber, and impermeable textiles that guarantee a long lifespan of usage. It features an independent footrest that ensures optimum lateral and frontal access, and the design of the armrest is based on observed postures assumed by the user while accessing or retiring from the product. The seat is designed to be used in low toilets, thereby reducing over exertion on the part of a user with reduced mobility. The chair also comes equipped with 600 mm wheels and an integrated break system (see Figures 10.8 and 10.9).

10.4.2.2 KOMFORTO—Furniture for Rest and Eating

Designed by Sara Avendaño, Diana Osorno, and Lorena Salazar, KOMFORTO is a chair designed to improve posture and increase comfort. It is made from impermeable material that does not retain heat. The inclination of the backrest and footrest is adjustable, thereby allowing different postures to be assumed. The chair comes equipped with a pouffe and an additional tray, thereby facilitating the work of staff (see Figures 10.10 and 10.11).

10.4.2.3 Patient Constraint System

Designed by Sandra Parra, Juan David Herrera, and Julián Vanegas, this is an abdominal and lower body restraint system that allows the user greater freedom of movement in bed or while resting in a chair. The system also guarantees increased safety for the user. It can be easily installed before or after the patient is in bed or using the chair. The lower part can be adjusted to fit any type of furniture and the part that secures the legs is placed on the patient's thighs (see Figures 10.12 and 10.13).

TABLE 10.1
A Description of the Stages of BABEL

Stages	Materials, Methodologies, and Activities
1. To Identify	
1.1 User characterization 1.2 Characterization of existing products designed for recreation and education 1.3 Characterization of the context 1.4 Formulation of design problems, needs, or opportunities 1.5 Development of the project's conceptual references	• Review of existing bibliography as a theoretical antecedent in order to establish reference points. • Photographs of the study population during their daily activities. • Anthropometric analysis. • Surveys intended for parents, psychologists, teachers, and visually impaired children. • Analysis of inconsistencies found in existing resources in: form, material, functional, dimensional, relationship of use, etc. • Observation of resource implementation in Colegio de Ciegos y Sordos de Medellín (CIESOR) in order to analyze and understand the needs of this particular population. • Identifying the user's characteristics within school and domestic contexts: interpersonal relationships with classmates, teachers, and family members, movement and dynamics within these spaces, user's activities within the context.
2. To Evaluate	
2.1 Identification of a specific problem	• Establish a hierarchy of possible solutions to identified problems. • Inductive analysis of the problem appreciation stage. • Appreciation of the market's shortcomings regarding the products analyzed in phase 1. • Identification of a specific problem (there are no recreational objects intended for visually impaired children that contribute to their educational development). • Selection of the best solution based on existing needs. • Design requirements are established based on analysis of the results.
3. To Integrate	
3.1 Concept of design 3.2 Design alternatives	• Proposal of design alternatives that meet the requirements found when identifying the problem. • Brainstorm. • Evaluation of proposals according to design criteria and use criteria. • Development of sketches based on the established requirements.
4. To Elaborate	
4.1 Final design specifications 4.2 Detailed technical design 4.3 Construction of a formal and functional model	• Definition of the production system: materials, productive processes. • 3D modeling of parts. • Development of technical computer-designed blueprints. • Development of 1:1 scale mockup (material: carton).

(*continued*)

TABLE 10.1 (Continued)
A Description of the Stages of BABEL

5. To Validate	• Evaluation of the prototype by the user (the product as a quality control measure). • Development of a list of recommendations, suggestions, and solutions regarding the mockup based on the evaluation.
6. To Produce	• Based on the previous evaluation of the product, the prototype is developed keeping the final recommendations in mind.

Note: A description of the stages of BABEL—recreational objects to support the learning process of visually impaired children: imaginary friends. According to the methodological application of ergonomics and as a parallel and analogous process.

TABLE 10.2
A Description of the Stages of the Design for Elderly People: Ergonomics Applied to the Development of Technical Aids

Stages	Materials, Methodologies, and Activities
1. To Identify	
1.1 User characterization 1.2 Characterization of existing products in the nursing homes 1.3 Characterization of the context 1.4 Design problems, needs, or opportunities	• Review of existing bibliography, documents, and previous studies. Structured interviews. Katz index of independence of everyday human activities. Minimum mental function exam (MMSE). • Study literature on the user's anatomic-physiologic and psychological characteristics and compare them to the users present in the geriatric homes. • Biomechanical analysis based on photographic records of body postures. • Study the anthropometric characteristics of a representative sample of the user population in the homes: measurements were taken from the following design relevant segments: head, hand, foot, reach, bipedal, and seated posture: Protocols of the International Standards for Anthropometric Assessment. Statistical Program SPSS. • Analysis of the visual and functional inconsistencies. Search for documentation. Lists for determining usability, safety, degree of autonomy in the use of objects, dimensions communication, etc. Photographic records.
2. To Evaluate	
2.1 Specific problem 2.2 Objective specifications	• Establish a hierarchy of problems. • Adaptation from the quality function deployment (QDF). Design techniques centered on the user.
3. To Integrate	
3.1 Concept of design 3.2 Design alternatives	• Approximately describe the product's technology and the principle of function and form. • Brainstorming. Ulrico and Eppinger's 5-step method. • Brainstorming. Morphological configuration method. User-centered design techniques. Implementation of design criteria. • Evaluation and establishing a hierarchy of the alternatives according to ergonomics, usability, and accessibility. • Modeling.

TABLE 10.2 (Continued)
A Description of the Stages of the Design for Elderly People: Ergonomics Applied to the Development of Technical Aids

4. To Elaborate	
4.1 Final design specifications 4.2 Detailed technical design 4.3 Construction of a formal and functional model	• Adaptation of the quality function deployment (QDF). Design techniques centered on the user. • Technical calculations, computer-assisted design software (CAD). Methodology for the synthesis, similarity, analysis, and inspiration for the materials section. • Prototype.
5. To Evaluate	• Technical trials. Functional trials. Checklist on usability, accessibility, safety, degree of autonomy for using the object, dimensions, communication, etc. Photographic records, structured interviews.
6. To Produce	• Manufacture.

Source: From Sevilla, G. and González, J.F., Diseño para el adulto mayor. La ergonomía aplicada en el desarrollo de ayudas técnicas. Paper presented at 14a Semana de la Salud Ocupacional, Medellín, Colombia, 2008. With permission.

Note: According to the methodological application of ergonomics and design as parallel and analogous processes.

FIGURE 10.8 ANPHIBIA: the chair used for personal hygiene activities. (From Sevilla, G. and González, J.F., Diseño para el adulto mayor. La ergonomía aplicada en el desarrollo de ayudas técnicas. Paper presented at 14a Semana de la Salud Ocupacional, Medellín, Colombia, 2008. With permission.)

FIGURE 10.9 ANPHIBIA: the chair as a support mechanism when using the toilet. (From Sevilla, G. and González, J.F., Diseño para el adulto mayor. La ergonomía aplicada en el desarrollo de ayudas técnicas. Paper presented at 14a Semana de la Salud Ocupacional, Medellín, Colombia, 2008. With permission.)

FIGURE 10.10 The KOMFORTO system: a chair with an eating-table and an auxiliary chair for nurses. (From Sevilla, G. and González, J.F., Diseño para el adulto mayor. La ergonomía aplicada en el desarrollo de ayudas técnicas. Paper presented at 14a Semana de la Salud Ocupacional, Medellín, Colombia, 2008. With permission.)

FIGURE 10.11 The user's relationship with the KOMFORTO system. (From Sevilla, G. and González, J.F., Diseño para el adulto mayor. La ergonomía aplicada en el desarrollo de ayudas técnicas. Paper presented at 14a Semana de la Salud Ocupacional, Medellín, Colombia, 2008. With permission.)

FIGURE 10.12 Patient constraint system. (From Sevilla, G. and González, J.F., Diseño para el adulto mayor. La ergonomía aplicada en el desarrollo de ayudas técnicas. Paper presented at 14a Semana de la Salud Ocupacional, Medellín, Colombia, 2008. With permission.)

FIGURE 10.13 The user's relationship with the patient. (From Sevilla, G. and González, J.F., Diseño para el adulto mayor. La ergonomía aplicada en el desarrollo de ayudas técnicas. Paper presented at 14a Semana de la Salud Ocupacional, Medellín, Colombia, 2008. With permission.)

10.5 CONCLUSIONS

The following conclusions can be drawn from the above presentation, analysis, and examples:

- Both ergonomics and design aim to improve a user's well-being, health, and safety.
- The product—from both a design and ergonomic perspective—demands a process of observation, analysis, application, and verification, which should include the components of the user-product-context system.
- Using methodology, it is possible to establish parallels between ergonomics and design and integrate them into product design processes.
- Ergonomics can be used as an analysis tool in the design process.
- Design can be expressed as an application instrument of ergonomic analysis.
- Design is one of the possible results of ergonomic intervention.
- The anthropocentric, systematic, and interdisciplinary perspectives of ergonomics also form part of the design process.
- Ergonomics should not be seen as a resource exclusively at the stage of configuration; it should be present throughout the whole design process.
- The subject units and activities proposed by the methodology become areas of study for teaching (undergraduate and post-graduate), think-tanks, graduate projects, and consulting services for companies that wish to incorporate ergonomic conditions into their products, goods, and services.

REFERENCES

Cross, N. 2002. *Métodos de diseño. Estrategias para el diseño de productos*. México, DF: Editorial Limusa, S.A. de C.V.

De Montmollin, M. 2000. *Introducción a la ergonomía, los sistemas hombres-máquinas*. México, DF: Editorial Limusa de C.V.

Sáenz, L.M., Prada, M., Sanín, J.D., Arbeláez, E., Mesa, A., Ossa, J., Valencia, A., et al., Facultad de Diseño Industrial, Escuela de Arquitectura y Diseño UPB. 2009. Modelo disciplinar de la facultad de diseño industrial. Universidad Pontificia Bolivariana, Medellín, Colombia.

Fornari, T. 1989.*Las funciones de la forma*. México: Universidad Autónoma Metropolitana Azcapotzalco: Tilde Editores.

IEA Council. 2000. International Ergonomics Association (What is Ergonomics). http://www.iea.cc/browse.php?contID=what_is_ergonomics (accessed January 5, 2010).

Karwowski, W. 2006. The discipline of ergonomics and human factors. In *Handbook of Human Factors and Ergonomics* 1–3, 3rd edition, edited by Gavriel Salvendy Purdue University West Lafayette, Indiana and Tsinghua University Beijing, People's Republic of China. United States of America: John Wiley & Sons, Inc. On line version in Willy Interscience http://www3.interscience.wiley.com/cgi-bin/bookhome/112467581/?CRETRY=1&SRETRY=0 (accessed January 5, 2010).

Konz, S. 2006. Principios que se recomiendan para diseñar el trabajo: bases científicas. In *Diseño de sistemas de trabajo*, 211–19, México: Editorial Limusa, S.A de C.V., Grupo Noriega Editores.

Lotero, A.M., and Henao, M. 2009. Amigos imaginarios. Project for graduation in Industrial Design Faculty. Facultad de Diseño Industrial, Universidad Pontificia Bolivariana, Medellín, Colombia.

Maldonado, T. 1977. *El diseño Industrial reconsiderado: definición, historia, bibliografía*. Barcelona: Gustavo Gilli.

Max Neef, M., Elizalde, A., and Hopenhayn, M., et al. 1986. *Desarrollo a Escala Humana*. Santiago de Chile: Cepaur.

Press, M., and Cooper, R. 2009. *El diseño como experiencia. El papel del diseño y los diseñadores en el Siglo XXI*. Spanish edition. Barcelona: Editorial Gustavo Pili.

Sáenz, L.M. 2005. *Ergonomía y diseño de productos, criterios de análisis y aplicación*. Medellín: Editorial Universidad Pontificia Bolivariana.

———. 2006. Fundamentación conceptual y metodológica – línea de investigación en ergonomía – Versión 3. Grupo de Estudios en Diseño, Facultad de Diseño Industrial Universidad Pontificia Bolivariana, Medellín, Colombia.

———. 2006. Methodological proposal for learning, research and application in ergonomics and products design. Paper presented at IEA 2006 Congress. Meeting Diversity in Ergonomics, July 10–14, in Maastricht, Netherlands. Elsevier Ltd.

———. 2008. En el proceso de diseño: alternativa metodológica para la concepción de productos. *Iconofacto* 4 (5): 170–82.

Sáenz, L.M., and Sevilla, G. 2007. Investigación en ergonomía & diseño, productos para usar. Paper presented at 13a Semana de la Salud Ocupacional, Medellín, Colombia, November, 2007.

Sanín, J.D. 2005. Método general de diseño, el diseño como un mecanismo de adaptación artificial. Fundament for Disciplinar del Diseño Industrial Facultad de Diseño Industrial, Universidad Pontificia Bolivariana, Medellín, Colombia.

Sevilla, G., and González, J.F. 2008. Diseño para el adulto mayor. La ergonomía aplicada en el desarrollo de ayudas técnicas. Paper presented at 14a Semana de la Salud Ocupacional, Medellín, Colombia, November, 2008.

Universidad Pontificia Bolivariana. 2004. *Proyecto institucional*. Medellín: Editorial Marín Vieco.

Valencia, A. 2007. *La estructura: un elemento técnico para el diseño*. Medellín: Editorial Universidad Pontificia Bolivariana.

Vidal, M.C. 2002. *Ergonomia na empresa. Útil, pratica e aplicada*. 2a ed. Rio de Janeiro: Editora Virtual Científica.

11 Design, Usability, and Maintainability of Consumer Products

Lawrence J. H. Schulze

CONTENTS

11.1 INTRODUCTION

The purpose of this chapter is to provide a roadmap, of sorts, through the process of consumer product design. The focus will be on the product life cycle, the steps within the product life cycle, including product usability, and steps often not discussed in most treatises regarding these being maintenance and retirement. In addition, in this chapter, system and product are used interchangeably. Why? All products are subsystems that have an overall goal (mission). As such, the product (system) user is an integral part of the system, without which the designed subsystem (product) could not realize its defined goal (mission).

11.2 CONSUMER

A consumer by definition is an entity that consumes for direct use or ownership rather than for business. A consumer may also be a heterotrophic organism that ingests another organism or organic matter in a food chain (American Heritage Dictionary 1993). A consumer, in this case, is an individual who wants/desires a thing that will fulfill some psychological/psychosocial desire leading to the fulfillment of a goal and/or desire.

Usually, the consumer is the end user of the product, there being no further modification or processing involved other than some assembly work. Consumer products are usually purchased locally from a retailer by an individual. No purchasing agents or persons trained in buying things are involved. There are seldom any specifications involved in the purchase. Consumer products are normally purchased in small quantities, in contrast to the bulk purchases of commercial or industrial products. Consumer products are distributed through a long channel with many steps between the manufacturer and the consumer who is at the end of the chain. Consumer products are usually used in or around the home, in a residential or social setting rather than in a workplace environment.

Users of the products may be any age, gender, or physical condition and may have widely varying educational, cultural, or economic backgrounds (Hunter 1992). All are driven by the interface by which humans interact with these devices (user interface). User interfaces have a dual function; a platform for the quality of the human–device interaction and carrier of the system's attractiveness and purchasing appeal (Bauersfeld, Bennett, and Lynch 1992).

Consumers of products are changing their methods of consumption. They are becoming more informed in choosing products and more demanding about what those products should be like, especially in light of their access to the World Wide Web (WWW). Ranganathan and Ganapathy (2002) provide an interesting discussion of the key dimensions of business-to-consumer web sites that have revolutionized both the marketing and consumption of consumer products.

Consumers are also taking a more active role in the marketplace than ever before. As a result, researchers in consumer product development, human factors researchers, in particular, are finding new and sometimes overwhelming demands placed on them by companies who are striving to meet the new consumer's need. However, while companies are starting to catch on, the push for change in human factors research has not kept pace due to rapid prototyping and manufacturing access provided through globalization. Knowing what the competition is up to and what retailers want is vital to successfully marketing a product; companies need to pay more attention to the end user.

11.3 PRODUCT DESIGN

Human factors has become concerned with understanding the design process for two main reasons. First, there is a concern for optimizing the design process, to reduce the effects of chance and errors in design. Secondly, there is the concern to incorporate the requirements of the end user as early as possible when design is relatively fluid. It is argued that this process is product independent (Stanton 1998).

There are three distinct, but not mutually exclusive areas in which human factors should be considered relative to the conceptualization and design of consumer products: safety, operability and maintainability, and attractiveness. In safety, the product should not be designed in such a way that it could fail and cause harm to the user as a result of something unplanned, uncontrolled, or sometimes undesirable (Anton 1989). In operability and maintainability, the product should be easy to operate and maintain, and in attractiveness, the product should be admirable and desirable, but without compromising safety, operability, or ease of maintenance (Woodson, Tillman, and Tillman 1992).

Often, there are many design alternatives to select from when designing a new product. Choosing the optimum one can be difficult when each looks equally good on paper. For example, the use of mockups and prototypes offers the design staff a relatively inexpensive and fast way to test these alternatives. Prototypes and mockups can be used to test safety, usability, and comfort. The term "prototypes" and "mockups" can cover a range of functionality, from low-level up to full-function models. However, mockups are generally smaller and less complete versions of the actual product. As hardware can be a mockup, so too can software. Mockups are relatively inexpensive to produce, because only part of the system is simulated. Mockups are particularly well suited to iterative testing, where the design is tested, changed based on the test result, and then tested again. Because of the low cost and low complexity, numerous variations of the design can be mocked up and tested in a short time.

Reducing a system's weight and size has been a growing trend in the marketplace. System integration and miniaturization has become one of the most distinct trends of modern technological development today, especially in the electronics industry where miniaturized mechanical components and assemblies, called micro-systems, are typically employed (e.g., the iPod). However, as mechanical components and assemblies become smaller in size and lighter in weight, structural mechanics-related problems, such as vibration, fatigue, reliability, control, moisture exposure, and noise become more problematic. In order to properly address these problems to improve mechanical design capabilities, specific modeling, testing, and analysis techniques, and expertise tailored to such micro-mechanical systems need to be developed. It is necessary, therefore, to develop modeling, testing, and analysis capabilities and control methodologies so that potential problems can be anticipated, minimized, and eliminated at the design stages of micro-systems.

Essentially, there are three major steps in the process of designing a system for use, operation, and disposal. These steps are: (1) preliminary (initial) design, (2) critical (conceptual) design, and (3) final design. However, there are a number of activities (sub-steps) that are associated with these major steps. These activities are enumerated and discussed below.

11.3.1 Define System Objectives

System objectives should be general, not specific, to avoid constraining creativity. Many individuals may see these as defining the mission and vision of the final system; what the consumer product is to do and whom it is to do it for.

11.3.2 Define System Requirements

In defining system (product) requirements, the capabilities, accuracy, safety, and constraints (environment within which the product will function) need to be taken into consideration in all three steps of the design process. Each evolution of product design through initial, critical, and final design should re-evaluate these system requirements to ensure that they have evolved with each iteration of the product in the design cycle.

11.3.3 Define System Functions (Function Analysis)

After the system requirements have been determined, system functions need to be defined. These system functions are described at three levels. Level 1 determines the functions of the product that are necessary under normal operating procedures and environments. Level 2 determines the functions necessary when the system malfunctions. A recent example of a failure of level 2 would be the non-fail-safe conditions that occurred during the Trans-Ocean owned, and British Petroleum (BP) leased drilling platform accident that happened in the Gulf of Mexico in April 2010. Only one blow-out preventer was attached to the oil well. The blow-out preventer failed, resulting in a massive release of oil into the Gulf of Mexico that endangered both fishing and recreational activities of states along the U.S. Gulf Coast. Level 3 determines the management of the system operations and includes the evaluation of correct operating procedures and the determination of new operating procedures if the initial operating procedures prove to be ineffective and/or inefficient under both normal and system malfunction conditions.

11.3.4 Allocation of System Functions (Interface)

The allocation of system functions relates to what actions will be controlled by the system (product) and what actions will be controlled by the operator (product consumer). This is an important step in determining the level of unburdening (the action of off-loading operations responsibility from the operator to the system) that anticipates the activities normally assigned to the user and relegates these operations to the system. As advances in expert systems improve, this type of unburdening improves and is related to user focus group input into the design of consumer products. These focus groups (discussed subsequently) also determine the level of mechanization and automation that is built into consumer products. For example, iPods are designed to re-shuffle music selections based on the listening history of the user.

11.3.5 Selection of Displays and Controls

The selection of displays and controls providing information to the product user (consumer) and the controls that they use to interface with the product are important and may rely on age, gender, and cultural information provided by product evaluation during the three design phases. The perception, understanding, compatibility, and integration of displays and controls are integral to all phases of the design cycle. Perception of displayed information as well as controls (activation symbology) will determine the usability of consumer products and the level of satisfaction users have with consumer products.

The correct interpretation of the information presented to the user (including user manuals) will also determine the appropriateness of user actions (decisions), the acceptability of those decisions by the system, and the acceptability (usability) of the product as a whole. It is also important to consider the selection of controls and displays that will support perception, integration, and decision making that may take place quickly, especially in emergency and/or system malfunction conditions.

11.3.6 Design of the User Place/User Environment

The design of the user place/user environment is focused on the placement of controls and displays where they can be seen, heard, and used by the appropriate operator. Such displays may be designed for either the parallel or serial presentation of information. Parallel presentation of information implies the presentation of multiple sources of information on multiple displays. An example of such information presentation would be using multiple displays with either laptop or desktop computer systems, where the user can display primary document sources while displaying information associated with particular files and/or applications (e.g., displaying document files and email accounts on different displays at the same time).

The formatting of such displays is, now, predominately under user control. That is, the user determines the configuration of information that is shown on the display(s). As electronic technology improves, the ability of consumers to configure user display and control interfaces improves. This is exemplified by both the iPhone and the iPad.

Assuring control-display compatibility is also important in the design and usability of consumer products. Configurations, either under or outside consumer control, are based on user experience, user expectations (population stereotype based on cultural and experiential expectations), user and designer knowledge, and user skill.

Other important user environmental issues in design that are related to usability (the following section) are communication (user instruction and user feedback), satisfaction during product use, motivation for product use and providing user feedback to designers, and cohesiveness of user-product interactions. These aspects are important considerations that directly relate to product "usability" evaluations by the user and can translate into feedback for product modification and improvement.

Product characteristics that are directly related to user assessments of "usability" and that are directly related to product design efforts are: the location of controls and displays as they relate to product use; the location and access to operable parts such as battery access and replacement, ease of product operation, and ease of product repair by the user. Within the last decade, reparability has given way to disposability where it has been cheaper and/or more convenient to replace a consumer product than have the product repaired. However, in light of the more recent concentration on recycling and green design, reparability is now coming back into fashion.

11.3.7 Empirical Evaluation of Alternative Designs

The empirical evaluation of alternative designs has moved into the framework of contextual evaluation. Scenarios are developed in laboratory-supported environments of potential use in which products are tested and assessed by potential user groups. Feedback from such evaluations are fed back into the product design process to represent user evaluation, in attempts to provide products that meet the needs of target user groups. Experimental designs and tests (laboratory and/or field) are developed to provide more appropriate feedback to designers before the product is actually manufactured for consumer consumption. These efforts are done to limit re-design efforts and, hopefully, provide products that consumers are more willing to accept and purchase. It should be noted that the results of such evaluations are only as good as the “representation” of the test groups to the potential consumer groups in the target market.

11.3.8 Development and Selection of Training Procedures

The development of training procedures (user manuals) is focused on three areas. These are instructions to users regarding weaknesses (limitations) of the products and to instruct users not to use products under these conditions (warning of misuse). Instructions are provided (if actually read and reviewed) to aid in the ease and efficiency of operation of the product. There is a litany of literature regarding the efficacy of providing user manuals for use, as it is human nature to rely on user innate ability to understand product use. As is now common, computers are purchased and delivered to consumers without user manuals; they are available on-line if installation and operation problems are encountered. Furthermore, in the age of globalization, user help desks are often located outside the user’s location of use. In such cases, users find attempting to obtain assistance using such off-site help services frustrating and often resort to trial-and-error or finding assistance by other means. It would be advised that user manuals be provided that focus on communication in terms of non-familiar system users, concentrating on error limitation, reduced product start-up time, reduced down time, and reduced system maintenance. Although green efforts are designed to reduce the use of “paper” manuals, software-based manuals with keyword searches would be an efficient and convenient way of providing information to end users that would not illicit stress during product installation, start-up, and/or use.

11.3.9 Implementation of Design

The implementation of product designs should follow prototype and field-testing evaluations of each design resulting from each stage of product design. These implementation efforts include product redesign, based on focus group feedback, evaluation of user comments and user product ratings, and evaluation against alternatives.

11.4 PRODUCT DESIGN FOR USABILITY

The integration of the principles of human factors has evolved significantly. Companies have become sensitive to the need for easy to use products primarily by the pressure placed on them by the marketplace. Prior to this recent concern for usability, the common practice for most consumer products designers and manufacturers had been to concentrate solely on product appearance and consumer preference issues, while ignoring issues related to ease of use of the product.

When designing a product, consideration should be given to the activities of the future users: their perceptions, cognition, and actions. How people will interact with the product and what difficulties they may encounter is somewhat unpredictable (e.g., the Wii).

Kansei, meaning "graceful and looks intelligent, but no so expensive" in Japanese, is a method of product development that is consumer oriented. This concept was first applied to engineering new product design in Hiroshima University in about 1972 (Nagamachi 2002). The concepts revolving around this design approach are that there are physical traits of a product that must be understood and interpreted in the sense of how consumers will react to such physical traits of a product. Furthermore, the impact of these traits and the psychological reaction to these traits must be tested in an "ergonomic" experiment. Once these traits have been established through experimental analysis, the traits are then subjected to multivariate analysis in relation to consumer reactions to these traits. A model of Kansei engineering, adapted from Nagamachi (2002), is presented in Figure 11.1.

Scenario building or contextual design (Jordan 1998; Suri and Marsh 2000) is an important methodology in product design assessment. Scenarios are typically fictional portrayals of product use within user environments and address specific characteristics, events, products, environments of use, user profiling, task analysis, and systems ergonomics. An example of where such scenario building was not complete would be with the iPhone, where applications relating to exercising are available but where the phone fails when exposed to human sweat—a likely result of exercising. Scenario building can be done with prototypes at all levels of fidelity representing user experience with like and/or similar products and is invaluable in the evaluation of early design ideas. Scenarios should take into account users, goals, tasks, activities, contextual areas of use, communication, and individualism in product use. Product performance regarding these areas of importance should be evaluated by interdisciplinary teams.

Maguire (2001) discusses the human-centered design cycle prescribed by ISO 13407 (software development) that supports Jordon (1998) and is applicable to any product development activity. These key human-centered design life cycle activities are presented in Figure 11.2, which is adapted from ISO 13407. The importance of user-centered/human-centered design is to actively involve users and develop a clear understanding of user task requirements, which is essential to establish the criteria by which the system will be evaluated. In other words, the human-centered design process establishes the conditions for system/product testing and evaluation.

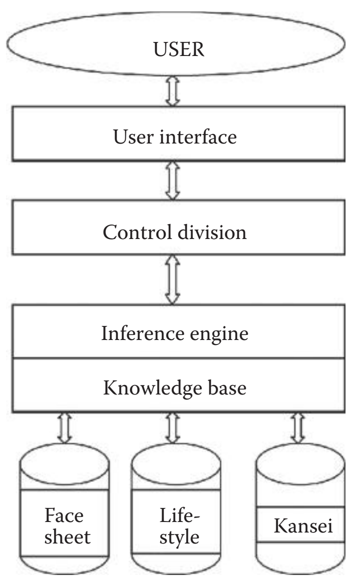


FIGURE 11.1 Kansei design model. (Adapted from Nagamachi, M., *Applied Ergonomics*, 33, 289, 2002.)

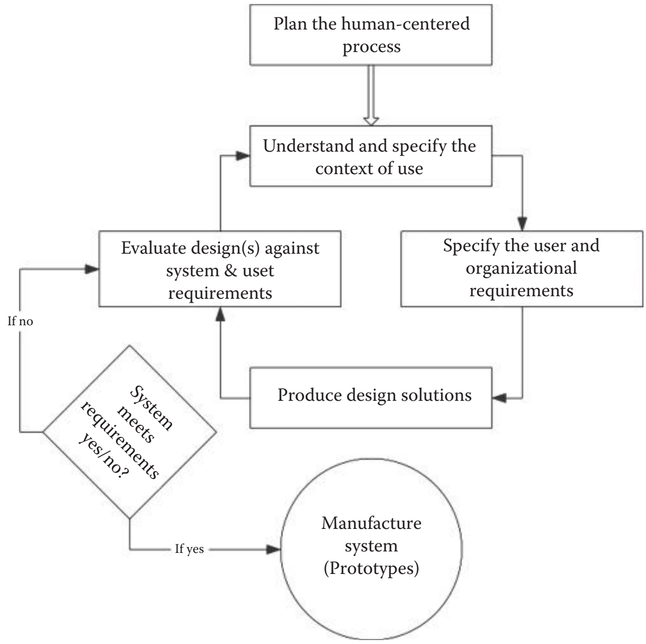


FIGURE 11.2 Human-centered design lifecycle activities. (Modified from ISO 13407.)

11.5 USABILITY

The first and perhaps most important stumbling block to usability is determining what makes a product usable. Different definitions of usability lead people to measure different aspects of product use. If usability is to be a universal concept, its basic constituents must be defined. *Learnability* (a system should allow users to reach acceptable performance levels within a specified time); *effectiveness* (acceptable performance should be achieved by a defined proportion of the user population, over a specified range of tasks, and in a specified range of environments); *attitude* (acceptable performance should be achieved within acceptable human cost, in terms of fatigue, stress, frustration, discomfort, and satisfaction); *flexibility* (the product should be able to deal with a range of tasks beyond those first specified; the perceived usefulness or utility of the product); *task* and *task characteristics*, which are the frequency with which a task can be performed and the degree to which the task can be modified (Stanton 1998).

When designing consumer products in terms of operability, designers should consider the adverse conditions to which their products might be subjected. Designing products for safe operation would include designing products that would fail safely. The designer must consider, in detail, how the product will be used by the operator and also how it is likely to be misused.

A special type of performance evaluation is that performed on the initial operational hardware. The fabrication of the prototype or initial production item of the new system is a milestone event. The prototype serves as the initial test vehicle, although others later in the production series may also be used for testing. The evaluation of the human factors adequacy of this prototype, sometimes called the first article inspection, is important for both the human factors specialist and the engineer because it is their first opportunity to deal with operational hardware. The equipment in this evaluation is operational hardware, but not necessarily functioning in an operational environment or in an operational manner. In general, first product inspection is performed within the manufacturing area. A number of researchers have specified factors that define or at least suggest high system usability. Although these criteria were developed to evaluate software interfaces, they can be

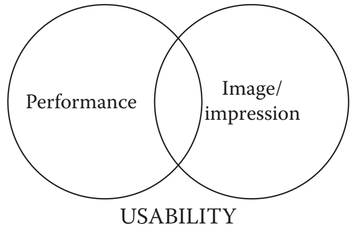


FIGURE 11.3 Holistic concept of usability. (Adapted from Han, S.H., et al., *International Journal of Industrial Ergonomics*, 28, 143, 2001.)

applied to any consumer product system with controls and displays. The set of factors are: learnability, efficiency, memorability, low error rate, and user satisfaction (Gordon, Liu, and Wickens 1998).

Han et al. (2001) have approached usability, the degree to which users are satisfied with a product, from both performance and image/impression dimensions. These authors, as with Nagamachi (2002), regard both design and usability as having significant psychological influences. These authors describe 23 performance dimensions that can be summarized under three basic categories. These categories are: (1) perception/cognition (understanding of the product interface); (2) learning/memorization (learnability of product operations); and (3) control/action (actual operation of the product). Twenty-five image/impression dimensions are also described by these authors and can also be summarized under three basic categories. These categories are: (1) basic sense (color, shape, texture appeal); (2) description of image (psychological description of appeal); and (3) evaluative feeling (how a person feels after using the product). This holistic concept of usability is presented in Figure 11.3.

Maguire (2001) intimates that product usability has its foundations in human-centered design. Product acceptance (i.e., usability) infers that the product is a well-designed system that provides information or a result that can be easily accessed/achieved and is presented in a format that is easy to assimilate and use.

Crilly, Moultrie, and Clarkson (2004) have stressed the visual domain and humans' judgment of aesthetics in product design. These authors have expanded on Shannon's (1948) theories and models of communication as they related to how product appearance communicates perceived attributes to consumers and is a significant determinant of product success and a consumer's assessment of product usability. The basic model communication adapted from Shannon (1948), and presented in Figure 11.4, recognizes that the communication channel (the means by which information is presented to the consumer) controls the interpretation and response to the information provided to the consumer; a gateway, so to speak.

A more expanded model representing the framework for consumer response to the visual domain in product design is presented in Figure 11.5. As can be seen from a review of Figure 11.5, a number of interacting levels and influencing characteristics are involved in the visual domain of product design. Internal as well as external factors influence consumers' interpretation of information regarding the design and presentation of consumer products. These factors range from the basic consumer senses to the integration of product and environmental attributes to elicit the appropriate consumer response.

FIGURE 11.4 Original basic model of communication. (Adapted from Shannon, C.E., *Bell Systems Technical Journal*, 27, 379, 1948.)

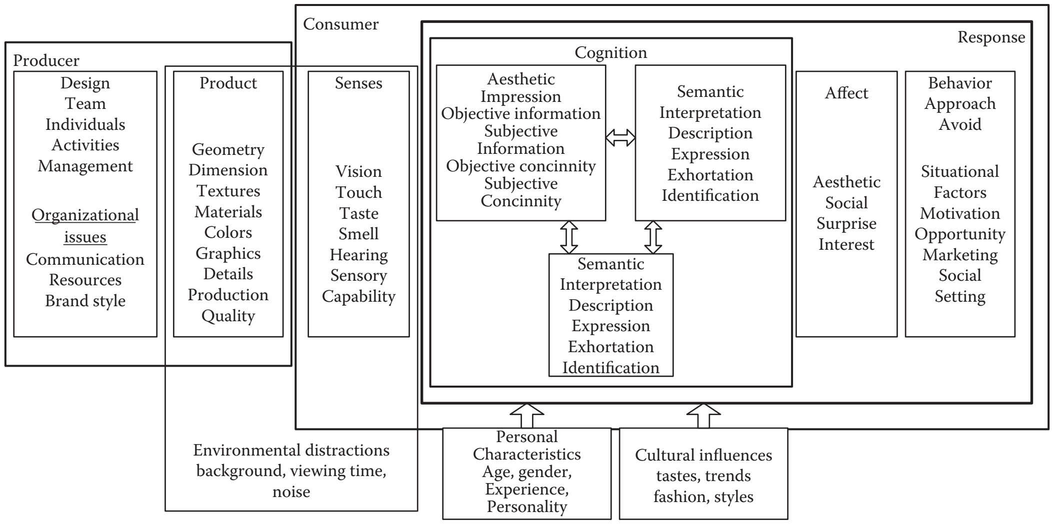


FIGURE 11.5 Framework for the representation of consumer response to the visual domain in product design. (Adapted from Crilly, N., et al., *Design Studies*, 25, 547, 2004.)

11.6 MAINTAINABILITY

In the most recent history of product design, products have not been designed for maintainability; rather, they have been designed for disposability. Examples are universal remotes for televisions and other audio-visual components to replace the remote that came with the original equipment (that failed) or to replace each of the remotes associated with each audio-visual component with one remote. However, as the movement toward sustainability and "green products" (whatever that means?) heats up, maintainability is now as important as it was during the years of industrial development.

Maintainability is an important concept that implies that consumer products can be maintained, either by the user or technician, so that the consumer product can be used continuously without replacement. Modern cars have been designed for efficiency of operations. However, by virtue of their design, a technician is required to understand the complexity of such systems, thereby making it difficult for direct user maintenance, save for changing oil and filters.

11.7 DISPOSAL

In recent decades, system disposal has been an often overlooked part of the design process regarding consumer products. Because of the cost of production vs. the cost of repair, it has been commonplace to replace a "broken" consumer product, rather than suffer the delay and cost of product repair. However, with the recent focus on recycling and environmental sustainability, manufacturers are re-focusing on the disposal process by providing end users with written instructions on proper product disposal and recycling. However, the major impediment to recycling efforts is convenience for the user. There are many regulations regarding what items can be recycled and where those items can be "dropped off."

Users of laser printers are familiar with promotional opportunities from retailers that offer a benefit (discount) for returning "spent" laser cartridges. However, such promotions are few and far between for most consumer products. Products requiring the use of DC batteries provide "proper" disposal information. However, if these options are not convenient to end users, "proper" disposal methods are most likely ignored. Therefore, it is recommended that if system (product) disposal after its useful life is to be sustainable, disposal and/or recycling opportunities need to be made convenient to system (product) end users.

REFERENCES

American Heritage College Dictionary. 1993. 3rd edn. New York: Houghton Mifflin Co.

Anton, T.J. 1989. Basic principles of accident prevention. In *Occupational Safety and Health Management*, 2nd edn., eds. A. Brown, L. Beamesdefer, and B. Boylan, 2. Boston: Irvin/McGraw-Hill.

Bauersfeld, P., Bennet, J., and Lynch, G. 1992. Striking a balance. Proceedings of the Conference on Human Computer Interaction (CHI'92), Monterey, CA, USA.

Crilly, N., Moultrie, J., and Clarkson, P.J. 2004. Seeing things: Consumer response to the visual domain in product design. *Design Studies* 25:547–77.

Gordon, S., Liu, Y., and Wickens, C. 1998. Software usability. In *An Introduction to Human Factors Engineering*, ed. P. McGreehon, 453–54. New York: Longman.

Han, S.H., Yun, M.H., Kwahk, J., and Hong, S.W. 2001. Usability of consumer electronic products. *International Journal of Industrial Ergonomics* 28:143–51.

Hunter, T.A. 1992. Design of consumer products. In *Engineering Design for Safety*, ed. R.W. Houserman, 104–5. New York: McGraw-Hill.

Jordan, P. 1998. Human factors for pleasure in product use. *Applied Ergonomics* 29 (1): 25–33.

Maguire, M. 2001. Methods to support human-centered design. *International Journal of Human-Computer Studies* 55:587–634.

Nagamachi, M. 2002. Kansei engineering as a powerful consumer-oriented technology for product development. *Applied Ergonomics* 33:289–94.

Ranganatham, C., and Ganapathy, S. 2002. Key dimension of business-to-computer web sites. *Information & Management* 39:457–565.

Shannon, C.E. 1948. A mathematical theory of communication. *Bell Systems Technical Journal* 27:379–423.

Stanton, N. (ed.) 1998. Product design with people in mind. In *Human Factors in Consumer Products*, 5–11. London: Taylor & Francis.

Suri, J.F., and Marsh, M. 2000. Scenario building as an ergonomics method in consumer product design. *Applied Ergonomics* 31:151–57.

Woodson, W., Tillman, B., and Tillman, P. 1992. Consumer product system. In *Human Factors Design Handbook*, 2nd edn, ed. H. Crawford, 132. New York: McGraw-Hill.

12 Assembly Complexity and the Design of Self-Assembly Products

Miles Richardson

CONTENTS

12.1 INTRODUCTION

Object assembly tasks are common in everyday life, from children's construction kits to adults assembling consumer products such as "flat-pack" furniture. Self-assembly consumer products have become increasingly common as they offer good value by reducing transport and labor costs (Madan, Bramorski, and Sundarraj 1995). However, there is evidence suggesting that self-assembly products can be difficult to assemble, leading to frustration, damage to the product, and injury (Richardson 2007). These issues and the prevalence of object assembly tasks in everyday life led Richardson et al. (2006) to study the factors that cause complexity during assembly. The methods used and factors identified have a theoretical basis in cognitive psychology and provide a tool to evaluate self-assembly product complexity and guidelines to control complexity.

This chapter will initially consider background information, such as the need for improved design of self-assembly products, types of assembly tasks, and a brief consideration of assembly instructions. Existing methods and guidelines of relevance, such as design for assembly (DFA), will also be considered. Subsequently, the evaluation of assembly complexity, its relationship to assembly object characteristics, and the work of Richardson et al. (2006) will be discussed. This includes the concept of task variables, guidelines to reduce assembly complexity, and a method to evaluate and predict assembly complexity. Finally, details will be presented that allow a bespoke assembly complexity formula to be produced.

12.1.1 Need for Improved Design of Self-Assembly Products

Self-assembly, or ready-to-assemble (RTA), products are very common. In a survey of UK consumers by the Office for National Statistics relating to just one type of self-assembly product, Richardson (2007) reports that 52% of adults (approximately 23–24 million) stated that they had assembled self-assembly furniture in the previous two years. Within these respondents, it was found that 67% reported some form of difficulty during the self-assembly process. Issues included accidents, such as consumers damaging the item that they were assembling (13% of respondents) or causing minor injuries to themselves (7.8% of respondents). When the large proportion of adults undertaking self-assembly tasks is considered, these percentages mean that approximately 3 million UK adults damaged the item being assembled and more seriously, a potential 100,000 people had required medical attention for injuries sustained during assembly. These findings make it clear that consumers do have problems with self-assembly consumer products, resulting in issues such as damage to the item or personal injury. Further, these differences can impact on the manufacturer or retailer, e.g., when consumers return the item to the store.

12.1.2 Types of Assembly Tasks

Before continuing, we should clearly define assembly. When considering the assembly of consumer products, we are considering products that require one-off assembly in the home, not batch assembly on a production line. Some factors that affect assembly complexity in both domains are likely to be similar, but the relationship may differ widely, owing to the nature of the tasks and the people involved.

The types of consumer product available for self-assembly in the home are numerous, from children's toys and play equipment, to all types of furniture, garden equipment, leisure equipment, and all manner of household objects. Many of these products have obvious safety implications, from children using self-assembly swings and bunk beds, to adults using self-assembly exercise equipment with heavy weights. Self-assembly trailers can also be purchased and used on the public highway. Sundarraj, Madan, and Bramorski (1997) refer to a trailer, purchased from standard retail distribution channels, which has 43 part types within a total of 200 parts. Self-assembly products can be highly complex with hundreds of component parts. One common factor is that the assemblies are likely to be one-offs. Even if the assembler is experienced, they are highly unlikely to receive training and will work from the procedural assembly instructions provided.

Assembly tasks in manufacturing differ markedly in terms of training and repetition. Here, training on a new assembly task is likely and the assembly is also likely to be repeated, meaning instructions if present become redundant. There is a body of research related to production line assembly, but the approach is related to productivity or worker health. The actual task of object assembly has received surprisingly little attention.

12.1.3 Design for Assembly

A method from the production line environment, but worthy of an overview, is DFA. Manual assembly typically accounts for 40%–60% of total production time and is often expensive and complicated. DFA is motivated by the need for product manufacturers to reduce their assembly time and costs (Chiang, Pennathur, and Mital 2001). The development of DFA can be traced back to predetermined motion time systems (PMTS) used to predict assembly time in the work place and based on external motor activities, rather than considering internal cognition. Helander and Willen (1999) note that these existing DFA methods and PMTS do not consider cognition and human information processing issues, such as perception, decision making, and action.

Although the focus of DFA is the production line, some principles are relevant to the design of consumer products requiring one-off assembly in the home. Andreasen, Kähler, and Lund (1983) detail how the assembly process can be broken down into operations that the design for ease of assembly should consider. Primary operations for consideration should be: orientation, transport, merging, and joining. This approach results in a number of component design principles for ease of manual assembly, including:

- Avoid assembly operations—integrate components
- Facilitate orientation—include orientation surfaces, make components symmetrical or increase asymmetry
- Facilitate insertion—make insertion unambiguous, design components with guiding surfaces

There are a number of techniques to evaluate DFA. Three of the better-known ones are those of Boothroyd-Dewhurst (USA), Lucas (UK), and Hitachi (Japan), which have all seen use in industry. These techniques are evaluative methods concerned with minimizing the cost of assembly on assembly lines and use their own synthetic data to provide guidelines and metrics to improve the design in its ability to be assembled (Boothroyd 1983).

The Hitachi AEM method analyzes the motions and operations, called "assembly operations," necessary to insert and secure each component of the product. A simple downward motion is considered to be the easiest and fastest assembly operation. Penalty points are awarded for every motion or operation that differs from, or is in addition to, this simple motion. The Lucas DFA method encompasses a functional analysis, a handling or feeding analysis, and a fitting analysis. The method involves the assigning and summing of penalty factors associated with potential design problems similar to the Hitachi method.

The Boothroyd-Dewhurst method initially involves reducing the number of parts and then ensuring that the remainder are easy to assemble. It enables the efficiency in terms of assembly to be evaluated and can be used to compare designs. The technique is based on an estimation of the time taken to handle and insert each component. Timings for handling are derived from a synthetic data chart with possible manual handling times based on measures of component characteristics, such as symmetry, thickness, and size, and assembly procedure issues, such as number of hands used and other handling factors. Similarly, the fastening or insertion times are estimated from a chart with categories for obstructed access, fastening type, resistance encountered, and subjective judgments such as ease of alignment. When all components have been analyzed, the estimated times are all added to give the total estimated assembly time. The efficiency is obtained by dividing a theoretical minimum number of components for the assembly by the estimated assembly time and multiplying by a constant (Boothroyd 1983).

The above methodologies are intended for use in the product design stage to ensure efficient assembly line production. Some of the issues raised are irrelevant in a home environment and the synthetic data they are based on is likely to be gained from a production environment once the task has been learnt. However, although biased toward motor activity, the DFA methods do offer interesting insights into the factors relevant to the one-off assembly of consumer products in the home.

12.1.4 Assembly Instructions

Before we progress, it is unwise to consider self-assembly without considering instructions. There is a small body of research into the design of procedural assembly instruction design (Hartley 1994) that considers the format of diagrams (e.g., Pillay 1997; Konz and Dickey 1969) and, more extensively, the relative benefits of diagrams and text (e.g., Bieger and Glock 1986; Booher 1975; Ellis, Whitehall, and Irick 1996; Stone and Glock 1981). More recently, Agrawala et al. (2003) detail an automated system for producing effective assembly instructions. The effectiveness of the instructions is ensured by an algorithm that is based on design principles derived from research into cognition during assembly. The design principles connect people's conceptual model of the assembly task to the visual representation of that task. The principles are also detailed in Heiser and Tversky (2003).

These principles and previous research allow Agrawala et al. (2003) to identify a number of design guidelines for creating assembly instructions:

- Hierarchy and grouping of parts: Assemblies are broken into a hierarchy of parts separated by either perceptual salience indexed by contour discontinuity or grouped by functions, e.g., the back of a chair. It is proposed that people prefer parts within a group to be added to the assembly either in sequence or at the same time.
- Step-by-step instructions: Assembly procedures should be presented in a series of diagrams. However, too many steps can be avoided by detailing repetitive actions in single diagrams.
- Structural and action diagrams: Action diagrams are superior to structural diagrams as they specifically depict the fastenings required in the assembly procedures. Structural diagrams present the components in their final positions, so diagrams have to be compared to infer which components have been attached.
- Orientation: This relates to the number of features visible and should facilitate object recognition and minimize erroneous positioning of components during assembly procedures.
- Visibility: All new components added during a step must be visible, although where repetitive assembly procedures occur, this is less important as long as one of the fastening procedures is identified. Visibility also requires context for positioning new components, therefore features of the assembly object must be visible.

The importance of instruction design is known and acknowledged, but Richardson et al. (2006) proposed that the assembly task and instructions are inextricably linked; fundamentally, instructions can only depict the object to be assembled. Even if all instructions are designed well, some products would still be more difficult to assemble than others. Given that the work of Agrawala et al. (2003) provides a method for automated instruction design, consistent good design of instructions becomes more likely. The focus then shifts to consider assembly object characteristics that make assemblies complex. An understanding of this allows the designer of assembly instructions to give attention to the depiction of difficult assembly procedures.

12.2 EVALUATING ASSEMBLY COMPLEXITY

It has been noted above that existing DFA methods are aimed at the production environment and do not consider cognitive aspects of self-assembly complexity. To design an easy-to-assemble product there is a need to understand what makes an assembly complex. It has also been noted above that while instruction design is important, it is the *structure* of the object to be assembled that ultimately impacts on assembly complexity. Therefore, the key question is what makes an assembly complex?

12.2.1 What is Assembly Complexity?

Complexity is inherent in a task and can be argued to be characteristics of the task that cause difficulty. Complexity and difficulty can be seen as synonymous as both are related to the inherent qualities of the task and impact on cognitive resources. Denis (1991) states that a cognitive operation is sensitive to the complexity or amount of information processed simultaneously. Pillay (1997) also supports the view that complexity is inherent in the task (and related to cognition). She proposed that assembly complexity can be related to the nature of the task and the demand placed on a person's mental effort, the cognitive load. The methodology of Richardson et al. (2006) detailed below uses physical characteristics of an assembly object (termed "task variables") that impact on cognition and therefore predict assembly complexity. Before this method is described, existing recommendations based on cognition are introduced.

12.2.2 Existing Self-Assembly Products Design Guidelines

A cognitive perspective of assembly is taken by Helander and Willen (1999), who provide a rare and informative overview of design for human assembly and suggest human factors principles based on aspects of human information processing, such as perception, decision making, and action. These are shown in Table 12.1.

An additional recommendation was proposed by Madan, Bramorski, and Sundarraj (1995), who found that difficulty in identifying parts could be reduced by packaging components into bags according to the order of assembly. Assembly time was reduced as the number of bags increased until 12 bags were used, at which point assembly time increased and the benefit of component grouping was lost. Such principles can be related to the methodology presented below, which goes a step further by providing a means to predict the complexity of an assembly or assembly step as depicted by the instructions.

12.2.3 How Assembly Object Characteristics Relate to Complexity

Richardson et al. (2006) detail research that provides the basis for the methodology presented below. Their premise was that the characteristics of the assembly object dictate the assembly instructions and relate to assembly complexity. They aimed to identify how the physical attributes of an assembly could be linked to cognitive workload and therefore assembly complexity.

The research into assembly task complexity began with a generic task analysis of assembly. The goal of object assembly was divided into identifiable sub-operations that were then linked to aspects of human cognition to hypothesize task variables (assembly characteristics) that could be linked to cognitive load and complexity. In the two experiments reported by Richardson et al. (2006), these physical characteristics of assembly objects, or "task variables," were systematically varied in a balanced fractional factorial and orthogonal design. Participants were observed carrying out

TABLE 12.1
Human Factors Principles in DHA

Why	What	How
Minimize perception time	Visible parts	Nothing hidden
	Visual discrimination	Size, color
	Tactile discrimination	Texture, size
Minimize decision time	Ease the formation of a mental model	Visible parts
	Reduce choice reaction time	Minimize number of parts
	Spatial compatibility	Collocation of associated items
	Visual, auditory, and tactile feedback	Assembly looks different, auditory and tactile snaps
Minimize manipulation time	Ease of manipulation	Fixture to hold parts, parts that are easy to grip and don't tangle, fasteners that are easy to use
	Physical affordances and constraints	Self-locating parts, increase tolerances
	Design for transfer of learning	New product similar to old

Source: From Helander, M.G. and Willen, B.A, *The Occupational Ergonomics Handbook*, CRC Press, New York, 1999. With permission.

a range of abstract and real-world assembly tasks that varied in their task variable levels and were comprised of different materials. To assess the complexity of each assembly, the time the participants spent thinking about the assembly was calculated. A clear relationship between the physical characteristics and assembly complexity was found in both studies and the regression model from the first experiment was able to predict the assembly complexity of the assemblies used in the second experiment. The regression model provides a tool to evaluate the complexity of assemblies or assembly steps defined by instructions. Such evaluation allows designers to keep the level of complexity at a reasonable level and could also provide a basis for self-assembly furniture standards.

This methodology and the predictive models of assembly complexity can be a tool for designers during the design and evaluation process to ensure self-assembly products are not too complicated for consumers. Such a process could be performed before the self-assembly product goes for more expensive user evaluation or to the marketplace. The methodology can also be used to inform consumers of the likely complexity of a self-assembly product and of the estimated time of assembly.

12.2.4 Task Variables

The task variables identified by Richardson et al. (2006) and found to be significant predictors of assembly complexity use definitions to operationalize them (for further details see Richardson et al. [2006]). These operational definitions can be used to score individual assembly steps as depicted by the instructions or entire assembly tasks and are listed below:

- Selections (S). The total number of components available to select from at the start of the assembly step or task being evaluated.
- Symmetrical planes (SP). The mean number of symmetrical planes measured in three planes, *X*, *Y*, and *Z* per component in the assembly step or task being evaluated.
- Fastening points (FP). The mean number of fastening points available per component in the assembly step or task being evaluated.
- Fastenings (F). The total number of fastenings required in the assembly step or task being evaluated.
- Components (C). The number of components added in the assembly step or task being evaluated (excluding fastening devices such as screws, nuts, and bolts).
- Novel assemblies (NA). The number of unique assemblies in the assembly step or task being evaluated.

12.2.5 Guidelines to Reduce Assembly Complexity

Clear conclusions can be drawn from experimental work of Richardson et al. (2006). All the task variables were found to relate to the complexity of assembly tasks to a degree, but three were particularly important: novel assemblies, symmetrical planes, and selections. Table 12.2 shows how a single unit change in each of the task variable levels can affect assembly complexity in a typical assembly.

Each task variable will now be considered in turn and related to the design of assembly items and their instructions.

The novel assemblies task variable counts the variety of components in an assembly. Variety leads to more unique assembly procedures and mental work, and therefore impacts on complexity. It can be recommended that each novel or unique assembly be given its own assembly step in the instructions. Also, in most instances, there is no need to depict an assembly more than once in the instructions.

Component symmetry is a good predictor of assembly complexity. A decrease in the level of symmetry relates to an increase in assembly complexity. Therefore, the orientation of components

TABLE 12.2
How Task Variable Levels Affect Assembly Complexity

Task Variable Showing Single Unit Change Direction + or −	% Approximate Change in Complexity
Symmetrical planes (−1)	30
Novel assemblies (+1)	15
Selections (+1)	6
Fastening points (+1)	4
Fastenings (+1)	4
Components (+1)	1

should be made easier, e.g., by including cues such as stickers to help people orient and rotate components correctly. If possible, components should be made symmetrical or any asymmetry made obvious. Assembly procedures involving asymmetrical components can be given their own assembly step in the instructions and isolated from other assembly procedures. Also, extra attention can be given to ensure that the two-dimensional instructions depict the orientation of the three-dimensional component in an unambiguous manner.

Holes for fastenings, or fastening points, provide cues for the positioning of components and should therefore be easily identifiable and distinguishable. A greater number of fastening points leads to a greater number of options for a component's position, greater choice and, therefore, a potential for error. In a step-by-step assembly, the number of fastening points starts off high and reduces as the assembly progresses. Instructions should ensure that the fastening points to be used are distinct and provide sufficient context to allow fastening points to be readily identified.

When using step-by-step instructions, components for subsequent steps are available for selection. The number of components available to select from increases choice and makes it more difficult to select the correct components. The clarity of the instructions can assist people in identifying the correct component, although there are other options. Components can be labeled physically with corresponding labels on the instructions; this can also facilitate orientation operations. Or the components can be grouped into a number of bags, with each bag providing the components for a single or small number of assembly steps, as depicted in the instructions.

When people see a lot of fastenings, their perception can be that the assembly will be more difficult, although in practice this may not be the case. Although a large number of fastenings could be depicted in a single assembly step and not affect complexity to a great extent, people's perceptions should be considered. The number of fastenings also increases the number of fastening points, so these should be kept to a minimum.

Finally, although an obvious factor, an increase in the number of components relates to only a small increase in assembly complexity, but does increase the selection issues highlighted above.

12.3 PREDICTING ASSEMBLY COMPLEXITY

The guidelines above can also be quantified and included in a formula that provides a method to evaluate the complexity of assemblies or assembly steps defined by instructions. This methodology provides a tool for the designers of self-assembly products and can ensure these products are not too complicated for consumers. Such predictions could also inform instruction designers so that they are aware of the complexity of the assembly at the start of the design process. The methodology can also be used to inform consumers of the likely complexity of a self-assembly product and of an estimated time of assembly. This could contribute to product selection and make consumers more aware of assembly requirements before they get the product home or start the assembly.

12.3.1 Example of Assembly Complexity Calculation

In order to evaluate assembly complexity, task variable levels are calculated for an assembly, or assembly step as defined by the instructions, and entered into the formula below. A generic formula is presented here, but for the greatest accuracy, further data collection should be considered. Those involved in the design and manufacture of self-assembly products can collect the data required to produce a bespoke formula suitable for use with their own products, and this process is detailed later.

The task variable definitions presented previously are used to calculate the task variable levels of the self-assembly product as a whole, or the elements involved in a particular assembly step. An example of how the task variable levels are calculated for an assembly is given below, for the abstract assembly shown in Figure 12.1.

The number of components (excluding fastenings) is given by counting the raw number of components. This results in a level of five for the components task variable in Figure 12.1.

The number of symmetrical planes is calculated by measuring the mean number of symmetrical planes measured in three planes, *X*, *Y*, and *Z* per component. In Figure 12.1, it can be observed that all five components have two symmetrical planes each. The level of symmetrical planes is therefore 2, $(2 + 2 + 2 + 2 + 2 = 10)$ divided by the number of components (5).

The number of novel assemblies is defined as the number of unique assemblies in the assembly step or task being evaluated. In Figure 12.1, all the assembly procedures are unique (none are repeated) and there are four occasions when individual components are combined, therefore the level of novel assemblies is four.

The number of fastenings is a simple count of the fastenings required in the assembly and in Figure 12.1 equals ten.

The number of fastening points is calculated by dividing the total number of fastening points by the number of components. In Figure 12.1 (from left to right), it can be observed that the first component has two possible points where a fastening can be inserted. The second component has three, the third component has five, the fourth component has seven, and the fifth component has three fastening points. The total number of fastening points (20) divided by the number of components (5) equals four.

The number of selections is the total number of components available to select from at the start of the assembly task. This would match the number of components if a complete assembly were being evaluated, but not if an assembly step as defined by the instructions is considered, as components for later steps would still be available for selection.

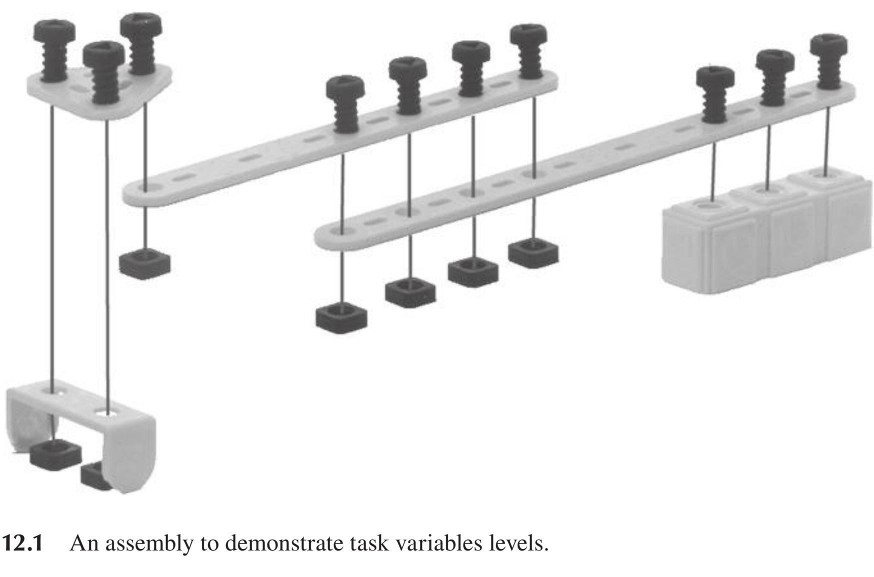


FIGURE 12.1 An assembly to demonstrate task variables levels.

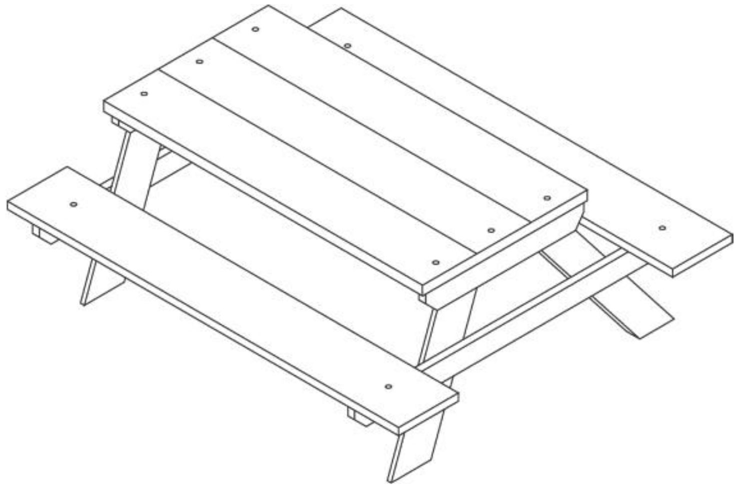


FIGURE 12.2 Picnic table.

When evaluating an entire assembly, the number of selections is likely to match the number of components. These figures are then entered into the generic formula below, or a bespoke version based on further data collection:

$$\text{Assembly complexity rating} = 10^{([0.020C]+[0.050NA]+[0.010F]+[0.100FP]+[0.020S]-[0.15SP]+1.200)}.$$

In this example, the complexity of four products is calculated (Figures 12.2 through 12.5). The task variable levels for each are presented in Table 12.3. This also shows the complexity rating

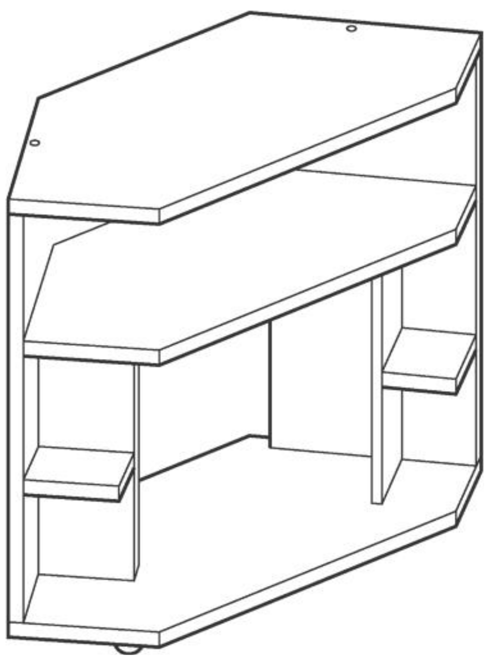


FIGURE 12.3 Corner unit.

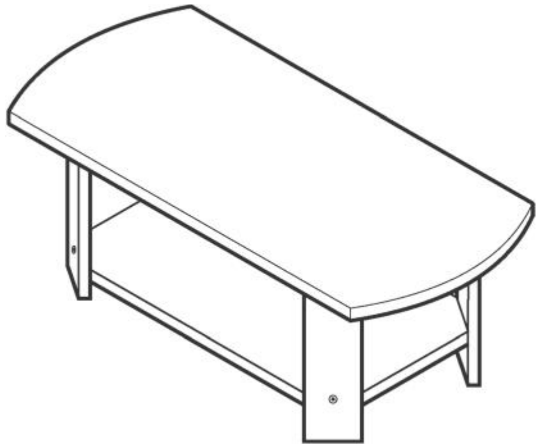


FIGURE 12.4 Coffee table.

produced for each of the four products when the task variable levels are entered into the generic formula. It can be seen that the picnic table is the most complex, followed by the corner unit. The coffee table and office chair are the least complex products.

12.4 PRODUCING A BESPOKE FORMULA

The example above uses a generic formula based on data collected from a range of self-assembly products and tasks. Those involved in the design and manufacture of self-assembly products should

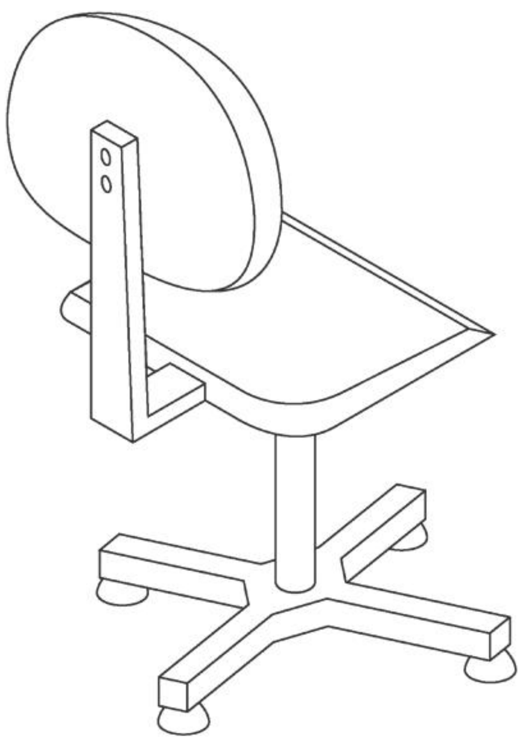


FIGURE 12.5 Office chair.

TABLE 12.3
Complexity Ratings for the Four Self-Assembly Products

Item	C	SP	NA	F	FP	S	Complexity Rating
Picnic table	14	1.57	5	25	1.79	14	160
Corner unit	9	1.56	5	20	2.89	9	116
Coffee table	10	2.10	4	14	2.80	10	80
Office chair	9	1.67	5	13	1.44	9	68

ideally collect their own data and produce a bespoke formula. The advantage being greater accuracy of, and confidence in, the predictions being made. In order to create a bespoke formula further data collection is required. The bespoke formula can then be used to predict the complexity of other items in the range, or the complexity of new items to be added to the product range.

12.4.1 Selecting the Test Items

The minimum number of assembly items required should be one greater than the number of task variables being considered. A sample of self-assembly products should be chosen that is representative of a product range that itself is based on similar materials and assembly procedures. The items chosen should cover a good range of task variables levels, e.g., both items with a high number of components and items with a low number of components should be included. What constitutes high and low is driven by the levels in the product range. If you are only interested in evaluating entire assemblies and not assembly procedures depicted by the instructions, then the selections task variable can be dropped.

The task variable levels are calculated for the selected items as described earlier. Once they have been calculated, the levels of correlation between the task variables should be calculated. If Pearson correlation levels exceed 0.8, action should be taken to reduce the level of correlation, by choosing a replacement item for example. A correlation level below 0.5 is acceptable. If correlation levels become a problem, task variables can be dropped. The fastenings task variable has been found to have less predictive power so should be the first to be considered for removal. The symmetrical planes and novel assemblies task variables are important factors so these should not be dropped.

12.4.2 Collecting Data

Once sufficient test items have been selected to cover the range of task variables, enough people need to be recruited to allow 10–20 observations per task variable used. Most authors recommend at least 10–20 observations per variable, otherwise the estimates of the regression equation are likely to be compromised. For example, 6 task variables would require 60–120 observations, which with 8 assemblies is 8–15 participants. This should be done in controlled conditions free from interruption. Participants should be informed that they will be presented with a number of separate assemblies in a random order. Data collection can take several forms, depending on the aims of the evaluation. It is possible to collect three types of data. Firstly, subjective ratings of assembly complexity from participants will allow perceived complexity to be predicted. Secondly, recording total assembly time will enable total assembly time to be predicted. However, total assembly time does not necessarily reflect complexity, e.g., a large number of repeat procedures are simple, but time consuming. This can be overcome with the third option where the time participants spend on fastening procedures during the assembly process is subtracted from the total assembly time.

Time spent on fastening procedures could vary widely for practical reasons, such as an individual's dexterity, and therefore can have little relationship to assembly complexity and mental effort. Fastening time is the time spent fastening components together, timed from when the components are ready for assembly or in the final position and the fastening process begins. Timing stops when fastening is complete or fastening actions pause, e.g., to check instructions. The remaining time is termed “thinking time” and is defined as all time excluding fastening time, such as time spent viewing the instructions, examining the assembly, or selecting and manipulating components. This is a more objective measure of assembly complexity as the remaining time reflects the time doing mental work, which is the time spent thinking, selecting, orientating, and positioning components ready for fastening. This third option for data collection requires the assembly process to be video recorded and played back for analysis. However, it does provide an objective prediction and evaluation of assembly complexity.

When collecting data, timing should begin when the participants are instructed to start the assembly. Timing stops when the participants are satisfied that the assembly is complete. At this point, subjective ratings of assembly complexity should be collected if perceived complexity is to be predicted. This is done by asking the participant to rate how difficult or complex they found the assembly on a scale from 1 to 9. The completed assembly is then collected and the next item provided until the participant has assembled all the test items.

12.4.3 Data Analysis

To examine the relationship between complexity ratings, assembly time, or thinking time and the assembly task variables, multiple regression analysis is used. The data should be entered into a statistics package in a format similar to that shown in Table 12.4, with a row of data for each observation and assembly when using multiple items. The columns provide data for each task variable used and the results of the data collection, complexity ratings, assembly time, or thinking time. When conducting the multiple regression, the complexity ratings, assembly time, or thinking time variables can be entered as the dependent variable in turn. The task variables are entered as the predictors. The unstandardized task variable coefficients and constant that are produced by the regression analysis are used to produce a regression equation that forms the formula for the prediction of assembly complexity, based on either complexity ratings, assembly time, or thinking time. The format of the regression equation will be

$$\text{Assembly complexity rating} = [x\text{C}] + [x\text{NA}] + [x\text{F}] + [x\text{FP}] + [x\text{S}] + [x\text{SP}] + \text{constant}.$$

TABLE 12.4
Example of Data Layout

Participant	Item	C	SP	NA	F	FP	S	Users Rating	Assembly Time	Thinking Time
1	1	14	1.57	5	25	1.79	14	8	957	361
1	2	9	1.56	5	20	2.89	9	6	887	245
1	3	10	2.10	4	14	2.80	10	7	652	199
1	4	9	1.67	5	13	1.44	9	4	641	175
1	5	18	1.00	12	38	1.68	18	9	1211	452
1	6	6	2.00	3	7	2.50	6	3	420	120
1	7	12	1.34	8	16	2.33	12	5	568	178
1	8	8	2.25	7	12	1.67	8	7	772	236
2	1	14	1.57	5	25	1.79	14	7	1004	395
2	2	9	1.56	5	20	2.89	9	7	896	233

12.4.4 Advanced Procedures

More advanced procedures exist that will lead to a more precise analysis. Firstly, a fixed dummy between subject variables can be used to identify each participant (Pedhazur 1982). These are entered into the first block of predictors and the task variables into the second block. This controls for variability due to individual differences and the unstandardized task variable coefficients from the second model are used. Secondly, it is likely that the distribution of the data collected may be skewed toward zero, in this case a log transformation can be performed, for example LOG(Thinking time). In this case, the multiple regression continues as described above, but the format of the regression equation will be

$$\text{Assembly complexity rating} = 10^{([x\text{C}]+[x\text{NA}]+[x\text{F}]+[x\text{FP}]+[x\text{S}]-[x\text{SP}]+\text{constant})}.$$

12.5 SUMMARY

The popularity of self-assembly products and the difficulties they cause consumers were highlighted at the beginning of this chapter and there is a clear need for good user-centered design of self-assembly products. This cannot be fully achieved without methods to evaluate and predict assembly complexity and the level of mental work an assembly will impose on the consumer. This chapter presents a unique research-based method to enable designers to evaluate and predict self-assembly product complexity during the design stage. This allows the design to be revised before the product enters the marketplace.

REFERENCES

Agrawala, M., Phan, D., Heiser, J., Hay-Maker, J., Klingner, J., Hanrahan, P., and Tversky, B. 2003. Designing effective step-by-step assembly instructions. *ACM Transactions on Graphics* 22:828–37.

Andreasen, M.M., Kähler, S., and Lund, T. 1983. *Design for Assembly*. Bedford: IFS.

Bieger, G.R., and Glock, M.D. 1986. Comprehending spatial and contextual information in picture text instructions. *Journal of Experimental Education* 54:181–88.

Booher, H.R. 1975. Relative comprehensibility of pictorial information and printed words in procedural instructions. *Human Factors* 17:266–77.

Boothroyd, G. 1983. *Design for Assembly Handbook.* Amherst: University of Massachusetts.

Chiang, W-C., Pennathur, A., and Mital, A. 2001. Designing and manufacturing consumer products for functionality: A literature review of current function definitions and design support tools. *Journal of Integrated Manufacturing Systems* 12:430–48.

Denis, M. 1991. Imagery and thinking. In *Imagery and Cognition*, eds. C. Cornoldi and M.A. McDaniel, 103–31. New York: Springer-Verlag.

Ellis, J.A., Whitehall, B.V., and Irick, C. 1996. The effects of explanations and pictures on learning, retention, and transfer of a procedural assembly task. *Contemporary Educational Psychology* 21:129–48.

Hartley, J. 1994. *Designing Instructional Text*, 3rd ed. London: Kogan Page.

Heiser, J., and Tversky, B. 2003. Cognitive design principles for visualizations: Revealing and instantiating. In *Proceedings of the 25th Annual Meeting of the Cognitive Science Society*, eds. R. Alterman and D. Kirsh, 545–50. Boston: Cognitive Science Society.

Helander, M.G., and Willen, B.A. 1999. Design for human assembly (DHA). In *The Occupational Ergonomics Handbook*, eds. W. Karwowski and W.S. Marras, 1849–65. New York: CRC Press.

Konz, S.A., and Dickey, G.L. 1969. Manufacturing assembly instructions: A summary. *Ergonomics* 12:369–82.

Madan, M., Bramorski, T., and Sundarraj, R.P. 1995. The effects of grouping parts of ready-to-assemble products on assembly time: An experimental study. *International Journal of Operations and Production Management* 15:39–49.

Pedhazur, E.J. 1982. *Multiple Regression in Behavioral Research*, 2nd ed. New York: CBS College Publishing.

Pillay, H.K. 1997. Cognitive load and assembly tasks: Effect of instructional formats on learning assembly procedures. *Educational Psychology* 17:285–99.

Richardson, M. 2007. Errors, accidents and self-assembly products. In *Contemporary Ergonomics 2007*, ed. P. Bust, 305–10. London: Taylor and Francis.

Richardson, M., Jones, G., Torrance, M., and Baguley, T. 2006. Identifying the task variables that predict object assembly difficulty. *Human Factors* 48:511–25.

Stone, D.E., and Glock, M.D. 1981. How do young adults read directions with and without pictures? *Journal of Educational Psychology* 73:419–26.

Sundarraj, R.P., Madan, M.S., and Bramorski, T. 1997. A customer-focus methodology for the manufacture of ready-to-assemble products. *International Journal of Operations and Production Management* 17: 1081–97.

13 Proposed Framework for Integrating Environmental Issues in Ergonomics to Product Development

Alma Maria Jennifer A. Gutierrez and Rosemary R. Seva

CONTENTS

13.1 INTRODUCTION

The whole world worries about the predicament of our planet. Documentaries such as the *Inconvenient Truth* and *11th Hour* focused on global warming issues and possible solutions to the climate crisis. In 2009, the Philippines experienced the effect of climate change when typhoon Ketsana struck severely flooding Metro Manila. During this disaster, many people died from drowning and much was lost in terms of properties and resources. The effects of the typhoon did not discriminate anybody. Rich and poor alike were devastated in the same manner. It was an eye-opener for policy makers and private institutions to act and reverse the effects of the climate crisis.

While it may be a good idea as part of a New Year's resolution to buy nothing this year to help with the garbage crisis and save money because of the economic crisis, it is an infeasible and unrealistic goal. The solution may be found in Bach and Rosner's (2008) book, *Go Green, Live Rich*, which espouses minimal consumption as a way of helping the environment. The book also promotes the purchase of environmentally friendly products that, although expensive, may be financially sound in the long run. By buying eco-friendly products, e.g., clothes, furniture, gadgets, and homes, people can minimize their impact on the planet and save a lot of money at the same time. However, environmental attributes, such as recycling materials and higher costs, have conflicting attributes with product performance, such as safety, material, consistency, and convenience (Chen 2001). Consumers may still prefer products with low environmental quality for quality reasons. Therefore, product development should address environmental issues and other needs of consumers who will buy and use these products. Acceptance by consumers is ultimately the most critical to the success of eco-friendly products.

13.2 LITERATURE REVIEW

13.2.1 Designing for the Environment

Product design is a critical determinant of a manufacturer's competitiveness. Incorporating environmental issues in product design and innovation is receiving significant attention from customers, industries, and governments around the world (Chen 2001). The earlier that environmental factors are considered in the product design life cycle, the greater the potential for environmental benefit and cost reduction. The increase in environmental consciousness has had a profound effect on consumer behavior with the green product market expanding at a remarkable rate (Schlegelmilch, Bohlen, and Diamantopoulos 1995). One survey found that 82% of British citizens rated the environment as an immediate and urgent problem (Dembkowski and Hanmer-Lloyd 1994). Based on these studies, there is a need to incorporate environmental attributes in product design and development. Consumers are now aware of the impact of pollution and other environmental damage in everyday life. There is an increase in environmental consciousness among consumers as can be seen in the products available in the market. There is a whole constellation of products that boast of being natural, preservative-free, biodegradable, fair traded, and healthy, but it can take quite a while to know what is truly good for you and the planet (Vartan 2006).

Many environmental attributes, such as fuel economy and recyclability, have effects that conflict with traditional product attributes, such as safety, material consistency, and convenience. Customers still prefer traditional products with low environmental attributes due to cost and performance considerations or skepticism. The current trend of green product development is dictated by consumers, stimulated by the government's regulations, and implemented by industries. Chen (2001) jointly considers the interactions of all three sectors in the marketplace. On the demand side, a conjoint framework was developed to model the purchasing behavior of green customers. On the supply side, theories in optimal product design and market segmentation to analyze the firm's strategic decisions regarding the number of products introduced and their corresponding qualities and prices were proposed. On the government's policy side, the model examined the relationship among environmental standards, the firm's strategies, and the overall environmental quality. The result of the study revealed that green product development and stricter environmental standards might not benefit the environment. As the environmental standard becomes strict, the firm may eventually lose its incentive for green product development and maintain the status quo of a traditional product.

Several efforts had been made to quantify the effect of a product on the environment. Eco-efficiency is defined as "the ratio of the value of a product to its environmental influence" (World Business Council for Sustainable Development 2010). It can be used as a tool in eco-design as it can make products—and the company as a whole—more valuable by promoting change toward sustainable growth (Park and Tahara 2008). Eco-efficiency is not only applicable in identifying the environmental aspects, but also other key issues of a product, such as quality, cost, and customer satisfaction. Quantifying producer- and consumer-based eco-efficiencies to identify key eco-design issues was the focus of the study. Their study computed for producer-based and consumer-based eco-efficiency, which were used to identify key eco-design issues. The computations considered not only the environmental aspects of the product, but other aspects such as product quality and consumer satisfaction. Application of this framework showed that it is possible to identify weak points of a product in relation to the environment, product quality, and consumer satisfaction. It was also pointed out that it is possible to design a product that is environmentally friendly while still maintaining a high level of quality and consumer satisfaction. The study illustrated that products can be eco-friendly and, at the same time, be of high quality to satisfy customers.

Integrating environmental concerns into the design process was the focus of the paper by Melnyk, Handfield, and Calantone (2001). They specifically delved into environmentally responsible manufacturing (ERM) as perceived and acted on by two critical groups within the design process. ERM has been defined as "an environmentally driven system wide and integrated approach to the reduction and elimination of waste streams associated with the design, manufacture, use and/or disposal of products and materials" (Melnyk and Handfield 1995). The first group consists of champions and supporters of ERM. These are people who either formally or informally act as advocates of ERM within the organization. The second group consists of the users of ERM tools and procedures. The result of the study revealed a strong gap between the ERM supporters and the users of ERM tools. The two groups were found to be separated by expectations, perceptions, and orientations toward ERM principles, practices, and tools. The study proposes a process map in order to integrate the environmental criteria into the design process. The steps were as follows: (1) soliciting support of an environmental champion; (2) defining environmental objectives; (3) selecting a project; (4) setting product launch goals and evaluating system; (5) getting support of team members; (6) providing the tools and training for design for environment; (7) monitoring the project; and (8) publishing and celebrating successes.

Eco-design and the 10 golden rules developed by Lutropp and Lagerstedt (2006) are a generic set of guidelines that have been developed as a collection of environmental design guidelines that are used in companies and academia. The foundation and motivation for their deployment was to fulfill the pedagogic need in eco-design courses at the Royal Institute of Technology (KTH) in Stockholm, Sweden. The 10 golden rules are generalized and must be customized according to the need of the product developer when integrating environmental attributes into product development. The 10 golden rules are enumerated as follows: First, avoid using toxic substances. Second, minimize energy and resource consumption in the production phase and transport through improved housekeeping. Third, use structural features and high-quality materials to minimize weight in product. Fourth, minimize energy and resource consumption in the usage phase. Fifth, promotes repair and upgrading especially for electronic products. Six, promote extending the life of the product, especially those that will significantly impact the environment. Seven, invest in better materials or structural arrangements to protect the product from wear and tear and prolong the product life. Eight, allow upgrading, repair, and recycling of the product through access ability, labeling modules, breaking points, and manuals. Nine, promote upgrading repair and recycling by using few and simply blended materials and no alloys. Lastly, use as few joining elements as possible, use adhesives, geometric locking, etc., according to the life cycle scenario. The 10 golden rules are organized according to the life cycle of a product.

The study by Waage (2007) presented a road map to guide the process of integrating sustainability and corporate social responsibility (CSR) into product decision and product design processes. The study proposed a framework for understanding the interrelations between a range of sustainability principles, strategies, actions, and tools and suggested criteria for considering products in terms of sustainability and CSR principles that draw on a systems-based and life cycle oriented approach. This study showed the importance of sustainability at the design stage of product development. Although companies may think that considering environmental issues in the design process may hamper product development and increase cost, it can have tangible benefits to the company, especially at present when governments are making policy changes to protect the environment. Even private companies and individuals want to do their share in this aspect. As such, integrating environmental concerns in product design can improve the salability of a product as it taps into the social responsibility of consumers.

13.2.2 Designing for Comfort and Safety

The studies mentioned previously illustrated the integral role of incorporating environmental attributes in product design and innovation. Together with this objective, however, consumer's needs for functionality, usability, safety, and aesthetics should be satisfied as well. Even if environmental issues have been considered in the design conceptualization, products might not be successful in the market because people are not willing to buy them. The authors have seen several designs of solar-powered cars that were conceptualized to solve energy problems. However, the constraints imposed by the new technology limit the comfort afforded to the driver, as well as the aesthetics. The car is functional but customers may not buy it until the design is improved to bring the level of driver's comfort to that of existing cars and address issues of safety.

The study by Hancock, Pepe, and Murphy (2005) provided a philosophical framework adopted from Maslow's hierarchy of needs. The foundation of the hierarchy is safety because it should ensure the well being of the user. A functional system, on the other hand, should enable the user to accomplish his or her desired goal. According to them, safety and functionality are two basic needs on which high levels of aspiration are based. Once functionality is achieved, usability facilitates performance by making sure that the user can accomplish the task. Usability develops a sense of trust and also improves the system by making it more memorable, learnable, efficient, and easy to use. These improvements are the basic elements for pleasurable interaction. They proposed a new term in the human factors vocabulary: hedonomics. Hedonomics is defined as "that branch of science and design devoted to the promotion of pleasurable human technology interaction" (Hancock, Pepe, and Murphy 2005). It stressed that the needs of the user should be fulfilled by incorporating an explicit recognition of motivation, quality of life, enjoyment, and pleasure into design. The goal of hedonomics is to design a system that will aid the user to live up to their fullest and unique potential.

The importance of pleasure in product design was emphasized in the book by Jordan (2002). He defined pleasure in the context of products as "Pleasure with products: The emotional, hedonic and practical benefits associated with products." Pleasure-based approaches to product design consider all the benefits that a product can deliver. He argues that there is an interaction between a person and a product. He proposes a framework, known as the four pleasures, which consider the different types of pleasure that people derive when using a product.

Today, consumers prefer a product that is consumer oriented because they want the products to suit their personality. Kansei engineering (KE) is a customer-oriented product development method developed by Nagamachi (2002). This method determines what the customers imagine or feel when they think of a certain product. KE was applied to different products, such as cars, refrigerators, digital cameras, hair care products, kitchen design, toilet seat design, etc. However, this study only focused on the needs of the consumer and failed to incorporate the impact of these products to the environment. Khalid (2006) proposes a new method that is comparable to KE. Citarasa engineering (CE) is a new design framework that elicits users' emotional intent, the meaning of the Malay term Citarasa. It is distinct from KE because it begins with the user's emotional needs, which are more explicit than the feelings considered in KE.

Quality function deployment (QFD) is another method used to integrate ergonomics in product design, such as the study by Haapalainen, Kivistö-Rahnasto, and Mattila (1999/2000) when they improved the ergonomic quality of pruning shears. User needs for pruning shears as well as the design aspects, which have the greatest influence on the ergonomic quality of pruning shears, were defined. The QFD application provides valuable information in the design process for hand tools and it can be used in the decision-making process during the design of hand tools.

Thatcher and Groves (2008) coined a new term to describe ergonomic intervention with a pro-environmental emphasis: "ecological ergonomics." Their study proves that the objectives of ergonomics are very much aligned with the objectives of design for environmental sustainability. A number of illustrations were presented on ergonomic interventions in the areas of domestic product design, interface design, training, and traffic flow design. It specifically emphasizes that ergonomic intervention already meets the criteria for being pro-environmental because it promotes an efficient, effective, and safe environment for humans. However, a number of issues were also presented. Such issues include: Is there a need to identify a specific term such as ecological ergonomics to describe interventions with an environmental focus? Where in the design cycle should ecological ergonomics focus? What are the acceptable measures for a pro-environmental outcome? On what theory must ecological ergonomics focus? These are the issues that need to be addressed and the authors believe that pro-environmental awareness should be incorporated in the ergonomics curriculum.

Previous studies presented the importance of integrating ergonomics in product design. Human factors add value to a product by making sure that they are easy to use and will not harm the user. However, ergonomics or human factors engineering only focuses on usability, efficiency, effectiveness and a healthy and safe environment. However, these studies still failed to consider the impact on the environment.

Hancock, Pepe, and Murphy (2005) and Jordan (2002) stressed the importance of pleasure when designing a product. They argued that the user's emotion should be taken into consideration because there is always an interaction between a product and a user. The product not only brings functional benefit, but also emotional benefit. Products elicit emotional responses from the user. If the user values the environment, then it can also trigger emotions as well. That's why it is very important to consider the pleasure that is derived when the user buys products that have environmental attributes.

The study by Thatcher and Groves (2008) is the closest in attempting to link ergonomics and environmental concerns. The study proposed a new term, but failed to propose a framework that designers can use when designing a product. Therefore, merging environmental attributes and ergonomics in product development is important for designers and manufacturers to gain an edge in the marketplace and lessen the impact on the planet.

13.3 GREEN ERGONOMICS MODEL

This chapter focuses on the product design process and the importance of incorporating environmental concerns and ergonomics while conceptualizing a product. The degree of satisfying a customer depends to a large extent on the quality of the underlying concept. Previous design frameworks failed to incorporate the importance of environmental attributes and ergonomics into the product development process, especially in the conceptualization stage. Figure 13.1 shows the green ergonomics model (GEM) that integrates the ergonomic and environmental attributes as input into the design process. Product designers must recognize the potential environmental problems early in the design stage. Ergonomic attributes must also be taken into consideration since these attributes will benefit the end user or consumer.

A product exists because the manufacturer or inventor sees that there is a need for it. It may be likened to a living object that people establish a relationship with (Jordan 2002). "Products can empower, infuriate or delight- they have personality" (Marzano 1998).

13.3.1 Ergonomic Attributes

Human factors practitioners focus on the importance of considering the needs of end users in the design process. A product's competitiveness can significantly increase by considering ergonomics in the design process. Vehicle companies use ergonomics as a means of attracting customers to buy their products, especially those that can afford to pay. Ergonomics is associated with comfort, for which some people are willing to pay a higher price.

One ergonomic concern in product design is safety as it is paramount in preventing harm and danger to the end user. Companies have a moral responsibility to ensure the safety of their product, especially in vehicle manufacturing. Safety is a distinctive competence of car manufacturers like

FIGURE 13.1 Green ergonomics model (GEM).

Volvo and is the primary reason customers opt to buy their products. Lack of safety, on the other hand, can severely stain a company's reputation, as in the classic case of the Ford Pinto, considered the worst car ever manufactured. During the seventies, Ford was so threatened by the emergence of Japanese cars in the market that they decided to match them with the introduction of the Ford Pinto. However, due to a design flaw, the Pinto tended to erupt in flames from rear-end collisions. Many people died because of this design flaw and it eventually ruined the company's reputation.

Ease of use or a "user friendly" product is not an added attribute nowadays, but a "must" when designing a product. When a customer buys a complicated product, a manual is usually provided because it is the only way that the designer can communicate to the customer on proper usage. However, users are not in the habit of reading manuals. Manuals are usually badly written, unattractive, and waste time. Moreover, users do not want to bring the manuals and consult them as the need arises. As such, they rely on their own understanding of the product or choose a product that is easy to use and understand.

A product's interface should be designed to facilitate understanding and prevent consumers from making mistakes while using the product. In the cellular phone industry, user-friendly design is a must because the lack of it can cause customers to shift to another brand. Nokia is known to be a user-friendly phone and some users are reluctant to try another brand because they are already satisfied and they do not want to incur the cost of re-learning another interface. Therefore, a user-friendly interface promotes customer loyalty through satisfaction.

The dashboard is the main interface that users interact with in a vehicle. It gives feedback to the driver on the status of the car and presents danger signals if needed. Essentially, dashboards should be easy to understand in order to prompt drivers to proper action. An unfriendly design can mislead the driver and cause problems.

Comfort of users is another important design criterion and is a part of ergonomics. This is especially useful for products that are used for long periods of time for which users experience discomfort, such as a chair. Time on task is a cause of musculoskeletal disorders and designing for comfort is the way to prevent these problems from occurring.

In a car, designers focus on seat and controls design to promote comfort. Seats are designed according to the contours of the body and allow adjustments in several dimensions. The controls are placed within reach of the driver in order to minimize reach and prevent driver confusion. Controls that are hard to reach can distract the driver because if they need to be manipulated, the focus of the driver will wander from the road. This is also true in the case of bad controls design. Drivers are in the habit of listening to music while driving and in doing so, they have to constantly operate the controls. If these controls are too far from the driver and are not user friendly, drivers can become engrossed in the process and forget the main task of driving.

Aesthetics appeals to the mind and emotion of the customer on seeing or using a product. It plays a crucial role in the success of the product because it is the customer's first encounter with the product. When a customer enters a shop to buy a specific item, they are usually attracted to unique and outstanding product characteristics, such as shape, size, and color. A potential vehicle customer in a showroom is drawn to the shiny color of the body, the unusual curves and lighting systems, and the capacity of the vehicle. Product characteristics allow customers to align their personalities with their vehicles. Some people think that small cars are cute and sporty while big cars are powerful and reliable. Good car aesthetics can spur the customer's interest and prompt them to inspect it closely to evaluate other features.

13.3.2 Environmental Attributes

Maceachern (2008) stressed the role of women consumers in the process of saving and protecting the planet earth. "Women are major purchasers of cars, electronics, appliances, furniture, cosmetics, clothing, food and sporting equipment. Also, fifty percent of purchasing agents for companies are women" (Maceachern 2008). The book's premise is that consumers can put a lot of pressure on manufacturing companies to be more responsible and conscious on the impact to the environment by patronizing eco-friendly products. If they are only willing to buy these kinds of products, it will force manufacturers to comply with environmental legislation and regulations because it is the way to the consumers' hearts.

In the vehicle industry, Toyota and Honda have responded to the call to address the issues of global warming and the increasing costs of gasoline by providing consumers with alternatives. They manufacture hybrid cars powered by electricity and gasoline at the same time. Other car manufacturers have seen the overwhelming response of consumers to these hybrid cars, which has motivated them to follow suit.

Recycling materials can help minimize the impact of solid waste to planet earth. According to Michael Lindfield, principal urban development specialist with the Asian Development Bank (ADB) Manila, "the growing volume and toxicity of waste is simply threatening to overwhelm our cities" (Ecenbarger 2007). Much of the wastes are from consumer packaging and the products themselves, all of which need years or even centuries to decompose. The ADB says that the growing garbage crisis must be countered by the 3Rs—reducing the amount of waste, reusing items that are now being discarded, and recycling materials. Taiwan and Singapore have adopted policies aimed at effectively reducing the volume of garbage. Officials in Singapore report an 8% drop in waste output since 2000, while the Taiwanese claim a 32% decrease in waste since 2001.

Households in Taiwan are required to dispose of waste every night at neighborhood pickup points. Trucks wafting classical music appear at street corners at designated times to collect compacted bagged waste that is sorted into kitchen garbage, trash and recyclable items. There is a fee for the garbage and trash bags, but the recyclables are taken at no charge. "There is a financial incentive to recycle," as Dr. Harvey Houng, advisor to Taiwan's Environmental Protection Administration (EPA), pointed out. Singapore is also working for private companies to reduce consumer waste. Its National Environment Agency has signed an agreement with five industry associations representing about 500 companies to substantially reduce packaging waste, which makes up about one-third of all household trash. "Many products are lavishly packaged to attract buyers' attention and affect their perception of the products," according to Dr. Yaacob Ibrahim, Singapore's Minister for the Environment and Water Resources. "In fact, it is not uncommon these days to come across packaging that is much more in volume and weight than the product itself." This statement should be a lesson for manufacturers to look into how they can minimize waste through improving the packaging and the product design itself without compromising the aesthetics and appeal of the product to the consumer (Ecenbarger 2007).

One way to address environmental issues in design is to plan to use recyclable materials at the onset of product development without sacrificing other important attributes such as product quality and durability. In doing this, unwanted waste can be transformed into a valuable resource. One problem in using recyclable materials is the tendency of the final product to be flimsy and unattractive. If manufacturers can address this quality problem, then the use of recycled materials can be more acceptable to consumers.

The use of electricity is prevalent in everyday life. If manufacturers and product designers can come up with products that use less or an alternative source of energy, then these could strongly diminish the impact on global warming. "Investment giant Goldman Sachs has already invested $1.5 billion in alternative energy and clean tech worldwide. Morgan Stanley estimates that global sales from clean energy sources like wind, solar, geothermal power, and biofuels could grow to $2 trillion by 2030" (Bach and Rosner 2008). Google has also joined the bandwagon and has invested tens of millions of dollars on research and development in renewable energy. Their hope is that it can help "spark a green electricity revolution that will deliver breakthrough technologies priced lower than coal."

Biodegrable materials can help in the global warming crisis since these materials can safely breakdown and will not harm the environment. These materials are found in most cosmetic and personal care products, such as soap, shampoos, lotions, hair dye, and tissue paper.

13.3.3 Consumer Response

The integration of ergonomics and environment in design is expected to improve customer satisfaction and eventually increase market share because these are the critical attributes that customers search for in a product. Although customers have unlimited needs and wants in a product, the attributes enumerated by the GEM are the most important ones and can make the difference when choosing between brands. Both sets of attributes can be used to market the products because it is the integration process that is the selling point of the framework and the eventual products that will be designed.

With the use of the GEM in the product design process, consumers become more satisfied because aside from functionality, comfort, and aesthetics, another dimension of human need is satisfied—social acceptance with the use of the product. In this day and age, people are clamoring for environmentally friendly products because the earth is in danger. Future generations may not be able to exist if humans continue to squander the gifts of the earth. Therefore, from this aspect, products that are designed using the GEM can have an advantage in the market.

Humans have a need for social acceptance and marketing people can use this need to conceptualize products were the GEM can be used. Not all products can be designed using the GEM because it is meant to be used for those products that are structurally complicated and use diverse resources.

As members of academia, we feel that we have a responsibility to do our share to save the planet earth. Through this research, we hope to inform the manufacturers and designers to consider the importance of integrating environmental attributes when conceptualizing a product.

13.4 CONCLUSION

Global warming has a great impact on our planet and no one will be spared the devastation it may bring. Rich and poor people have seen and experienced the wrath of Mother Nature in several past disasters. Providing eco-friendly products might be one of the numerous solutions for saving the planet from further destruction. Manufacturers have a social responsibility to provide products that will not damage the environment. Therefore, incorporating environmental attributes in product design and innovation is the key to sustainable development.

Although developing environmentally friendly products is essential, the development process should not underplay the needs of consumers, such as comfort and safety. Designing products that center on the activities and characteristics of a person is a basic ergonomic principle. Products should be easy to use and should not harm intended users.

This chapter proposes the GEM that integrates environmental and ergonomics issues into the product design process. This framework will be applicable during the conceptualization stage of the product. It is during this stage that the degree of customer satisfaction will depend. The model will be beneficial to product designers and manufacturers because it will give a product a competitive edge in the marketplace. Ergonomics issues include safety, comfort, and ease of use for the customer. Environmental issues, on the other hand, include the use of recyclable and biodegradable materials that help minimize the impact to the environment. If a product is eco-friendly, then customers feel that they are more environmentally responsible because they will not be contributing to the planet's destruction.

REFERENCES

Bach, D., and Rosner, H. 2008. *Go Green, Live Rich*. New York: Broadway Books.

Chen, C. 2001. Design for the environment: A quality based model for green product development. *Management Science* 47 (2): 250–63.

Dembkowski, S., and Hanmer-Lloyd, S. 1994. The environmental-value-attitude-system model: A framework to guide the understanding of environmentally conscious consumer behaviour. *Journal of Marketing Management* 19 (7): 593–603.

Ecenbarger, W. 2007. Its time to clean up. *Reader's Digest*, November, 29–35.
Haapalainen, M., Kivistö-Rahnasto, J., and Mattila, M. 1999/2000. Ergonomic design of non-powered hand tools: An application of quality function deployment (QFD). *Occupational Ergonomics* 2 (3): 179–89.
Hancock, P., Pepe, A., and Murphy, L. 2005. Hedonomics: The power of positive and pleasurable ergonomics. *Ergonomics in Design* 13 (1): 8–14.
Jordan, P.W. 2002. *Designing Pleasurable Products: An Introduction to the New Human Factors*. London: Taylor & Francis.
Khalid, H. 2006. Embracing diversity in user needs for affective design. *Applied Ergonomics* 37 (4): 409–18.
Lutropp, C., and Lagerstedt, J. 2006. EcoDesign and the ten golden rules: Generic advice for merging environmental aspects into product development. *Journal of Cleaner Production* 14:1396–1408.
Maceachern, D. 2008. *Big Green Purse: Use Your Spending Power to Create a Cleaner, Greener World.* New York: Penguin.
Marzano, S. 1998. *Thoughts.* Blaricum, The Netherlands: V+K Publishing.
Melnyk, S., and Handfield, R. 1995. Environmentally Responsible Manufacturing: New Challenges, Hidden Opportunities. Paper read at the Annual National Meeting of DSI, Boston, MA.
Melnyk, S., Handfield, R., and Calantone, R. 2001. Integrating environmental concerns into the design process: Explaining the gap between design and practice. *IEEE Transactions in Engineering Management* 48 (2): 189–208.
Nagamachi, M. 2002. Kansei engineering as a powerful consumer-oriented technology for product development. *Applied Ergonomics* 33:289–94.
Park, P-J, and Tahara, K. 2008. Quantifying producer and consumer-based eco-efficiencies for the identification of key ecodesign issues. *Journal of Cleaner Production* 16:95–104.
Schlegelmilch, B., Bohlen, G., and Diamantopoulos, A. 1995. The link between green purchasing decisions and measures of environmental consciousness. *European Journal of Marketing* 30 (5): 35–55.
Thatcher, A., and Groves, A. 2008. Ecological ergonomics: Designing products and systems to encourage pro-environmental behaviour. In *Fifth International Cyberspace Conference on Ergonomics*.
Vartan, S. 2006. Consumer news: Extreme makeover: Green Edition. *E: The Environmental Magazine* 17 (1): 54–55.
Waage, S. 2007. Re-considering product design: A practical 'road map' for integration of sustainability issues. *Journal of Cleaner Production* 15:638–49.
World Business Council for Sustainable Development. 2010. *Business Role/CSR Implementing SD Sustainable Value Chain* 2006 [cited June 6, 2010]. Available from http://www.wbcsd.org/plugins/DocSearch/details.asp?type=DocDet&ObjectId=MTgwMjc.

14 Cultural Ergonomics Issues in Consumer Product Design

Tonya L. Smith-Jackson, Hardianto Iridiastadi, and Chang Geun Oh

CONTENTS

14.1 INTRODUCTION

Human diversity has always existed, but it is only in recent decades that *consumer* diversity has experienced significant increases. By definition, consumers purchase or barter goods and services (APA 2007), so the actual consumer population increases as developing nations and sub-groups within nations acquire affluence and education, and trade facilitators, such as the Internet, gain prominence. Globalization has a very long history, dating back thousands of years with trade in spices, gold, food, livestock, and other commodities between tribes and nations. However, the most significant and traceable expansion of globalization occurred in the 1960s (Scholte 2000). Similarly, the growing heterogeneity of residents of different nations has presented new challenges to companies. Knowing this, any prudent manufacturer would realize that product safety, usability, sales, and brand loyalty have taken on several complex layers that can hinder product diffusion if left unattended or facilitate product diffusion if integrated with product design models.

These complexities are forcing designers to expand the inclusion of human attributes in the design, development, and evaluation of products. Unfortunately, researchers in marketing, as well as human factors and ergonomics, have on the whole, failed to realize the significance of cultural inclusion in their consumer product design efforts. Cornwell and Drennan (2004, 108) described the current state of affairs in research when suggesting that the "macromarketing field lacks a research agenda that adequately reflects consumer behavior writ large (and international)." Relevant knowledge domains, such as cultural psychology, have been treated differently by other specialty areas seeking to understand the phenomenon of culture. The interdisciplinary use of cultural psychology is not at a level that would significantly advance inclusive design. Valsiner (2001, 6) summarized the last 6 years of the integration of cultural psychology by stating that: "such historical integration has not happened, and psychology has been going around in a circle that has concentrated on temporary acceptance – followed by fierce denial – of the complex (higher, volitional) psychological phenomena as its legitimate targets of investigation."

14.2 CULTURAL ERGONOMICS DEFINITION

Given this state of affairs, it is important to understand specific design frameworks that address cultural differences when designing consumer products. One important framework is cultural ergonomics, defined as the assessment and application of cultural differences in the design and evaluation of products and systems (Chapanis 1974). Although Alphonse Chapanis introduced the concept over 35 years ago, few systematic research efforts have been implemented to ensure researchers and designers have a framework or tool from which to design for inclusion. Cultural ergonomics is not limited to products per se, in the traditional sense, but also includes designing for the environment. For instance, Talen (2006) describes the literature on how to design living spaces and places to facilitate collaboration among diverse ethnic groups. Her approach integrates cultural ergonomics, environmental psychology, and urban planning. Thus, cultural ergonomics is a methodology in its purest sense. A methodology is a research and design philosophy or approach that drives the research and design methods and analyses that will be used to achieve the goal of inclusive design.

It is important to describe major elements in order to place parameters around a methodology. Cultural ergonomics focuses on groupings that are grounded in cultural psychology, anthropology, and sociology. There are hundreds of definitions of "culture" throughout a variety of knowledge domains, but one definition that seems to be less difficult when operationalizing research constructs, systematizing design practice, and minimizing a Western-centric world view is offered by Veroff and Goldberger (1995, 10) as

> referring to a collectivity of people who share a common history, often live in a specific geographic region, speak the same or a closely related language, observe common rituals, beliefs, values, rules, and laws, and which can be distinctively identified according to cultural normative practices such as child-rearing, kinship arrangements, power arrangements, and ascribed roles that make up the fabric of how a society functions.

Cultural ergonomics differs somewhat from such terms as "universal design." Unlike universal design, cultural ergonomics is not focused on designing for ability ranges as they relate to physical, sensory, or cognitive disabilities. Individuals with disabilities prefer not to be labeled as a cultural group because group membership is solely focused on ability challenges arbitrarily selected by those with no apparent disabilities, rather than on individuals' identification with specific population groups that reflect their cultural heritage as a people (McDermott and Varenne 1995).

Another helpful description of culture is given by Hofstede (1997) in his useful analogy of mental software as a lens in which people derive meaning from the world around them, including their interaction with products or artifacts. We have referred to culture as a cognitive meta-schema supporting the view that culture is an information processing framework or scaffold that impacts an individual's interactions with the real world. Culture is the framework by which meaning and representations are attached to a product interaction, as well as decisions and assumptions made regarding product use. The meta-schema contains several specific schemas that, in turn, contain mental models. Mental models are used to understand how to use a product and the expectations we have about product function (Figure 14.1). Differences in meaning construction introduced by culture will influence how individuals' process information related to a technology or system (Smith-Jackson et al. 2005; Smith-Jackson et al. 2010).

A combination of the work of Hofstede (1997), Triandis (1995), and Hall (1966) yields a helpful list of cultural dimensions to design in a globalized or localized context (Table 14.1).

However, it is important to note that the cultural descriptors provided are not generalizable to all nations, nor does a single nation have the same cultural pattern. According to work by Howe and Strauss (1997), cultural descriptors are also becoming more diffuse intra-culturally by generations. For example, Generation Y in the United States has become even more individualistic while Baby Boomers have become more collectivistic (Tulgan 2009). Women in many nations tend to be more collaborative and less competitive when working in teams (Berdahl and Anderson 2005). Similar evolutions have been described in other nations such as South Korea. Sun-Young (2007) described

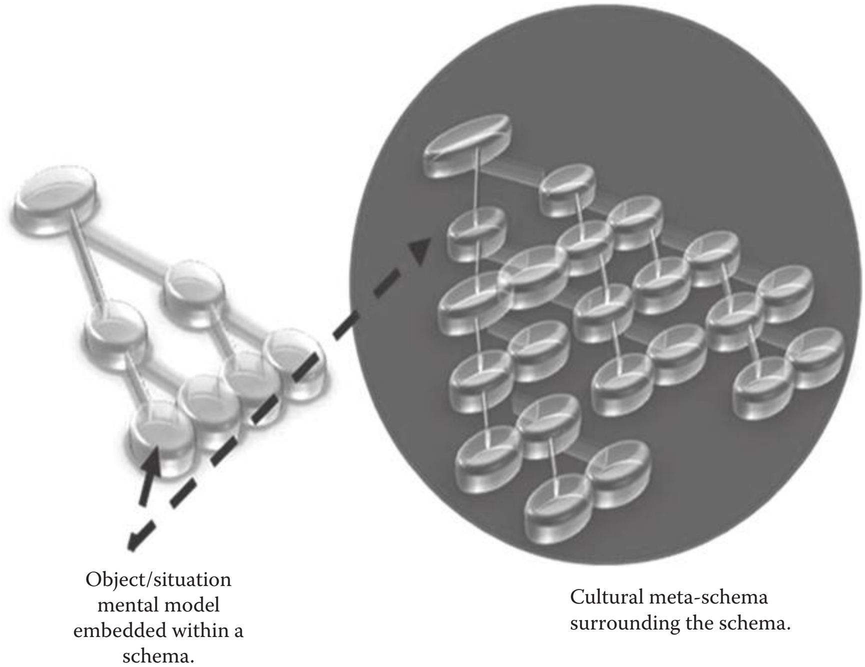


FIGURE 14.1 Illustration of a mental model embedded within a schema. Both are influenced by a cultural meta-schema (world view).

the historical and economic forces that have shaped the differences between the younger and older generations in South Korea, stating that political and social ideology was replaced by the values of consumerism. In addition, the lower access to jobs, popularity of traveling and living abroad, and high competition have shifted cultural values from group oriented (collectivist) to person oriented (individualist). Understanding the evolving nature of cultures by generations and the intra-cultural differences by such attributes as gender and class provide designers with a strong advantage when internationalizing and localizing products.

Table 14.2 summarizes the attributes of culture that are considered in cultural ergonomics to impact product usability, safety, and adoption. These considerations influence the "culturability" of the product, which is a term that combines culture and usability (Barber and Badre 1998).

Admittedly, cultural distinctions are not always clear, and every individual has multiple cultural attributes that interact in complex ways within a real-world context. The internalization of cultural attributes also varies from person to person. Some individuals identify very strongly with their ethnic group and may prefer certain color combinations, while others in that same ethnic group may not. Some individuals have strong religious beliefs that may dictate the types of icons or symbols that are considered acceptable or offensive. Ultimately, culture can only be derived by asking potential users who may participate in research and development to indicate cultures with which they identify and provide feedback about the look, feel, and functionality of the technology.

Additional complexities regarding culture are introduced when diversity exists within nations, such as religions, classes/socio-economic status, and ethnicity. Every nation has a dominant culture, or one that has accumulated proportionately more of the goods, products, services, and income of a specific nation. Dominant groups can be categorized as an interaction between gender, ethnicity, and nationality. Toward that end, it is important to note the potential to design only for the dominant group, at the expense of other groups who may be significant market consumers.

Despite the challenges, it is always useful to consider the cultural attributes of target groups and apply what is known about each to facilitate inclusive design. To apply this knowledge, it is

TABLE 14.1
Some Dimensions of Culture

Behavioral Relevance	Dimension	Description
Interpersonal styles	High context, low context	Reliance on non-verbal cues. Low: Non-verbal, implicit communication; High: Verbal, explicit communication
	High power distance, low power distance	Views of authority. Low: Egalitarian, shared decision making; High: Authoritative, decisions by rank
	Individualism, collectivism	Views of roles in group. Individualism: Single achievement; Collectivist: Group achievement
Process perspectives	Short-term orientation, long-term orientation	Time horizon. Short term: Immediate outcomes most important; Long term: Long-term impacts most important
	Polychronic, monochronic	Task-related behavior. Polychronic: Multi tasks, non-linear, time is relative; Monochronic: Single tasks, linear, time is absolute
	High uncertainty avoidance, Low uncertainty avoidance	Risk tolerance. High: Risk seeking; Low: Risk averse
	Masculinity, femininity	Application of gender-based values. Masculinity: Competition, outcome orientation; Femininity: Collaboration, process orientation

important to ensure that there is consistency between the cultural meta-schemas. Figure 14.2 is a simple flow diagram illustrating how design mismatches occur when designers fail to realize the importance of cultural differences. Design failures that arise from cultural mismatches can be avoided by using the appropriate methods.

14.3 INTEGRATING CULTURAL ERGONOMICS INTO THE DESIGN PROCESS

14.3.1 International Standards Organization Product Design

This chapter focuses on products broadly, so not all products involve human-computer interaction (HCI). For example, carrying equipment, construction ladders, and hand tools do not usually involve HCI design features. In essence, every product has an interface. There is always a component of the product that the user relies on to operate the product. As a demonstration, note the use of a ladder. Ladders have joints that can be used to read the position of the ladder to ensure proper placement. The angle of the joints tells the operator whether the ladder status is "safe." The joints are the interface, since they allow the operator to read outputs (joint position) to determine inputs (further manipulations of the ladder).

There are standards that, initially focused on HCI, are, in general, relevant to the usability of all products. A case in point is the International Standard for HCI and Usability provided by the International Standards Organization. Bevan (2001) provides a helpful overview of the numerous standards that apply to different aspects of product design. There are four features of these standards that are applicable to all products and that fit well within a cultural ergonomics methodology. These include (1) product use in context, (2) user interface and interaction, (3) user-centered process,

TABLE 14.2
Cultural Attributes Included in Cultural Ergonomics Methodology

User Attribute	General Description	Examples
Ethnicity[a]	Shared language, national origin, history (is not equivalent to race).	African-American, Korean, Indonesian, Ghanaian
Gender[b]	Identity and socialization as female or male (is not always consistent with biological sex).	Male, female, transgender, neuter
Nationality[b]	Country of origin, or in some beliefs, nation of ancestors' origin.	Mexico, America, Switzerland, India, China
Religion[b]	System of spiritual beliefs.	Buddhist, Muslim, Hindu, Christian, Lumumba
Generation[c]	Social group born in the same date range and marked by shared attributes such as the use of communication devices or linguistic markers such as slang.	Millennials, Generation Y, Generation X, Baby Boomers
Educational level[b]	Level of education attained within a structured learning system.	PhD, Baccalaureate, Preparatoria, Diploma
Socio-economic status[b]	Similar to social class; usually defined by income, education, location, and in some cultures, ethnicity.	Middle class, class minorities, upper class
Cultural area[d]	Regional or geographic area that has a relatively homogeneous group of residents.	Urban, rural, metropolitan, suburban, regional

[a] Betancourt and Lopez (1995).
[b] Descriptions derived from VandenBos (2007).
[c] Strauss and Howe (1997).
[d] Gupta and Ferguson (1997).

and (4) usability capability. Two examples are provided here to demonstrate how to integrate cultural ergonomics into the usability design process.

14.3.2 Product Use in Context

In a project to design an ergonomic work bench for weavers in Guatemala, Piegorsch (2009) used a participatory design process that ultimately led to a usable and adoptable design. Participatory design helped to establish the context of use. Interestingly, Piegorsch extended the context of use to socio-historical issues related to the educational system in Guatemala. The designers and participants chose not to design a formal training system to accompany the new design because anything resembling formal training had negative connotations for Guatemalans. As is the case for many countries, the educational system is perceived as a tool to indoctrinate and assimilate the indigenous or immigrant cultures into a dominant or majority world view. So, formal educational institutions are not perceived as preservers of indigenous culture. Any training to support learning to use the new design was left up to the expert artisans who would be dependent on informal apprenticeship methods to transfer knowledge. Other considerations made by the design team included an examination of the rocking postures during the weaving process and exposure to outdoor environmental elements. Unlike European cultures, weaving looms were not always used inside.

Another integration of cultural ergonomics into the context of use was conducted by Swart et al. (2009) who designed outdoor seating to facilitate interactions between older adults in

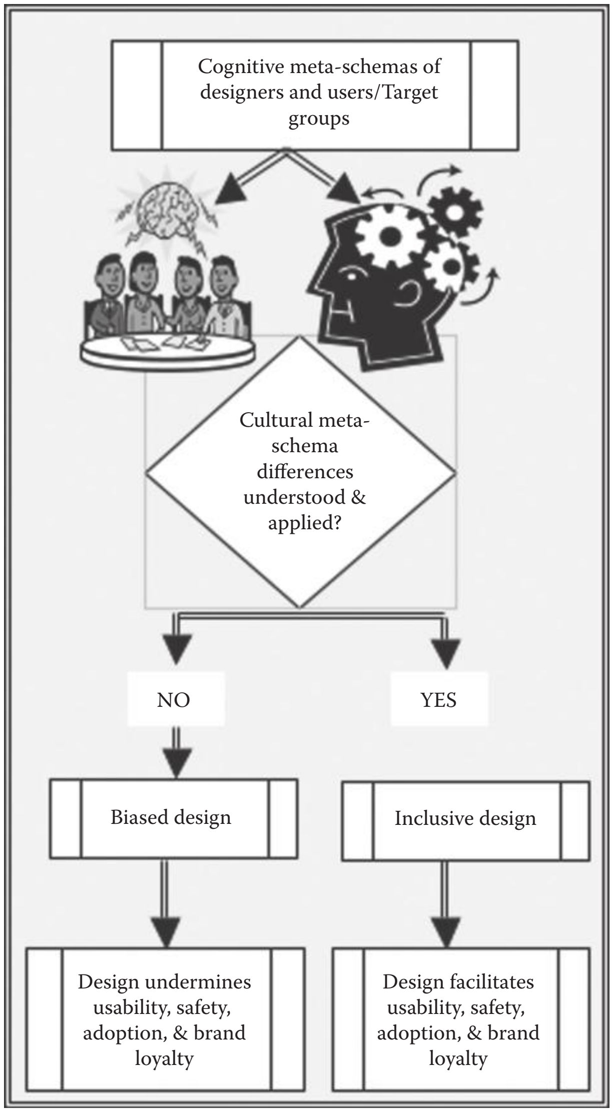


FIGURE 14.2 Flow diagram describing the role of the cultural meta-schema in product design.

social settings in the Netherlands. One factor they considered was "proxemics." Proxemics is the study of interpersonal communication as it relates to body distance when individuals are communicating. Some cultures have lower personal distances while others require higher personal distances (Hall 1966). The Netherlands is categorized as having a relatively higher personal space preference. To accommodate the sociological context of use, Swart et al. placed armrests on each bench seat. Rather than designing an open bench seat, the designers developed a personal space divider to give the perception of higher personal distance. Thus, instead of using anthropomorphic data to design the seating, the designers incorporated the cultural layer of personal distance.

Some researchers and practitioners have focused on educating students in human factors and ergonomics to consider the cultural context when designing so that they design a culturally competent pedagogy. As an example, Moalosi et al. (2007) helped students to elicit design factors by examining socio-cultural folk tales in Botswana. From an anthropological perspective, the folk tales reveal important perspectives and world views about person–person interaction, person–environmental and person–artifact interaction. Moalosi et al. (2005, 3) stated an important design perspective that designers should "focus on the intelligence of their users rather than the intelligence of their technology." Folk tales can reveal much about the intelligences (more than one type of intelligence) and values of a culture. Moalosi et al. (2005) offered five design criteria that should be applied when translating cultural information such as folk tale literal and figurative meaning to design features and functionality. The criteria are (paraphrased):

- The technology should have user interfaces and human interaction to support or facilitate users' cultural practices and customs.
- The artifact form or shape (look and feel) should correspond to the appropriate cultural aesthetics.
- The technology form or shape should convey emotional or affective norms of the culture, such as humor, joy, or limited emotional expression.
- The technology should evoke the types of feelings that users prefer when in certain contexts, i.e., desiring group achievement when in educational environments or individual achievement in the expression of art forms.
- The technology should be flexible and adaptive in the cultural context.

The use of stories and tales to elicit design information has become a relatively common practice. Moggridge (1993) was one of the earliest in interaction design to mention the importance of using storytelling as a method to extract user requirements and design considerations. Since users do not speak the language of design, richer data can be elicited by encouraging storytelling regarding the use of a product or something related to the product. A demonstration of this can be found in Lin et al. (2007), who focused on Taiwanese users who were aboriginal to Taiwan. Lin et al. (2007) developed a cultural product design model that illustrates the interdependencies of each step in the design process (Figure 14.3). The first two steps of the cultural design model are critical to extracting context-of-use factors for design. The first step was to consider context in the framework of economic, socio-cultural, and technology application. The second step was to use stories told by users to extract interaction patterns and mental models relevant to technology design.

Aryana and Zafarmand (2007) applied brainstorming to elicit mobile phone design information from consumers in Iran. An important point of the research was to demonstrate that designers should not assume that developing countries have the same design preferences or that countries in the Middle East have the same cultural values. These researchers found that, in contrast to collectivists, Iranians held strong individualist values, which differ from those of other nations in the Middle East. The method used to elicit design requirements was brainstorming, because this method conformed to cultural preferences. Rather than using a linear, step-by-step process with consumers, such as questionnaires or experiments, these researchers used brainstorming through informal sessions held with consumers. The style of data collection matched the polychronic values of Iranian culture. Design suggestions included novel ideas to enhance the sociability, aesthetics, and functionality of the phone.

As noted, gender is a cultural meta-schema that influences product usability. Green, Owen, and Pain (1993) provide a summary review of research on the socialization of technology by gender. For instance, the design of office products was described as being human-centered, but the dominant view of human-centered design was to design for "men" who represented proportionately more of the office environments in most countries until the 1970s, although some dominance continues today in certain countries. Therefore, design was predicated on the assumption of the needs and capabilities of men; but significant user groups are now dominated by women. As an example, Henwood (1993) discusses the assumption of designers that product models can be "feminized" to appeal to user groups that are predominantly female. The use of such labels as "soccer moms" described the modification of existing phone models to include features or functionality that appealed to women

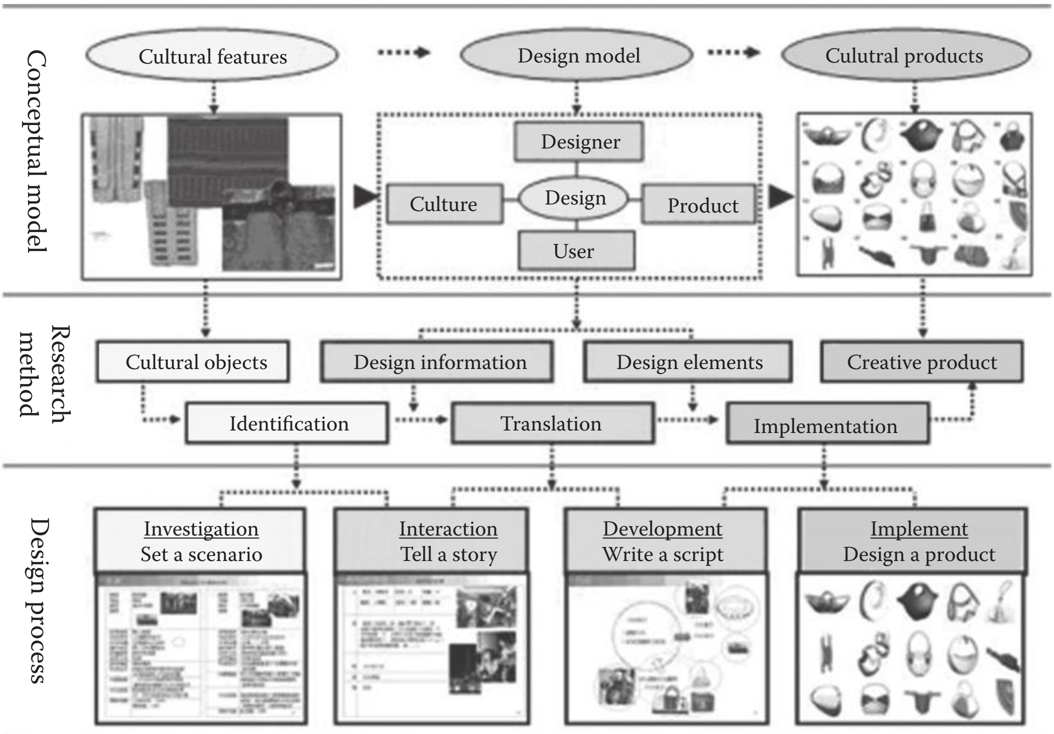


FIGURE 14.3 Cultural product design model. (From Lin, R., et al., *Usability and Internationalization, Part I, HCII 2007, LNCS 4559*, Springer-Verlag, Berlin, 2007.)

users. However, this design approach still communicates women as second-class citizens because the assumption is that men should drive the fundamental design elements of a product. These elements can be modified on a superficial layer to appeal to women users rather than designed from the ground up and inclusive of the needs and preferences of women users. A case in point is the common practice of designing products that are male-centric, but offering the product in different colors (e.g., razors, laptop computers, mobile phones) rather than giving serious consideration to redesigning the product in ways beyond superficial features.

Webster (1993) also offered a historical description of what may have accounted for the problems associated with usability of personal computers. One main contributor was the initial design of word processors such as Word Star. Word Star required the insertion of code or software control language to make documents. These features were introduced by the computer programmers who developed the software, most of whom were men. Thus, the mental model on which the Word Star interface was based was more compatible to men rather than women. Personal computer word processing packages continued this trend up to the late 1980s. The lack of usability for women contributed to occupational deskilling that introduced inequities in salary and promotion.

The design efforts highlighted here demonstrate the importance of context and the fact that many who design from a cultural perspective understand that context stretches beyond use of the technology in a micro-setting. Macro-factors such as history and socio-cultural attributes are also important contributors to the context of use.

To extract design features, it is important to use methods that are culturally competent, showing compatibility between the methods used and the mental representations and perspectives of the target users. The next section addresses the importance of appropriate methods that are compatible with the cultural ergonomics methodology.

14.3.3 User-centered Design Process

Like any methodology, there are methods that are accompanying methods. Similarly, as with many other design and research processes, the user-centered design process originated from a Western-centric world view. The goal in cultural ergonomics is to ensure that the methods used are compatible and valid in eliciting design perspectives from the target users. Methods that are not familiar to how users report information are not considered valid, since the traditional definitions of validity include the extent to which the methods used actually elicit the factors the designer intends to elicit. If a culture does not use questionnaires to self-report information, a designer who uses questionnaires to acquire usability ratings is likely to get invalid results. Many cultures do not report feelings, beliefs, or opinions using numerical magnitudes. It is essential that designers understand cultural views on self-reporting of constructs across cultures, rather than using the existing Western-centric empiricist/positivist methods. Imagine how the Borg Perceived Exertion scale (Borg 1970) or the NASA Task Load Index (Hart and Staveland 1988) could be rendered completely invalid if used with participants who do not envision a numerical label as a way to express the degree of physical or mental workload. Likewise, in the magnitude scaling of these self-report measures, the use of qualitative terms such as “light,” “very light,” “high,” and “low” may not directly translate into equivalent representations in other languages.

14.3.3.1 Instrument Design

The application of methods requires the design of instruments or apparatus to elicit information from users. The information can be objective, such as task completion time and accuracy when using low- or high-fidelity prototypes. The information can also be subjective, such as self-reports using questionnaires. In addition, the data resulting from the objective or subjective methods can be quantitative, where user data are revealed in the form of numbers or qualitative, where user data are revealed in words. Subjective rating scales are an example of a subjective, quantitative instrument. Gathering critical incidents by observing product use is an example of an objective (by observation) qualitative (notes) method. These distinctions are important, as they should be used to identify appropriate instrument designs for pilot testing.

When discussing psychometric theory and scaling, Nunnally and Bernstein (1994) emphasized the importance of ensuring that the instrument design is useful, repeatable, and generalizable. In cultural ergonomics, this is often the area of greatest weakness. Unfortunately, product design teams have administered instruments such as questionnaires to populations that may find little meaning in the scaling techniques. Magnitude matching, for example, is the foundation of Likert scales, but magnitude matching is not always compatible with the mental models that cultures hold about the strength or valence of opinions. Additionally, completing a questionnaire may seem impersonal. For example, Smith-Jackson and Essuman-Johnson (2002) found that Ghanaian workers preferred to discuss safety problems as a group rather than complete individual questionnaires to rate their safety climate. Although the researchers were using both methods, during questionnaire administration, several of the participants spoke aloud about their experiences. Similarly, Latino migrant farmworkers in a study in the United States showed the same occurrences, sharing information and talking aloud (Smith-Jackson, Wogalter, and Quintela 2010). It is almost as if, in a collectivist culture, a group automatically becomes a team, while in individualist cultures, a group functions as separate individuals who just happen to be collocated. In the empiricist view, “discussion” during administration is a threat to internal validity, yet this may not be the case from a cultural ergonomics perspective. Shared agreement may be more valid and useful than individual opinions in some cultural contexts.

Whether questionnaires, focus groups, informal gatherings, or experiments are used, there are response styles that seem to be associated with culture. For a comprehensive discussion of these styles, see Johnson et al. (2005), who examined response styles in 19 countries. Designers should be aware of these styles and use them to make informed decisions about elicitation of design information from different cultural groups. Extreme response style is the tendency to select only the ends of rating scales, e.g., selecting either the highest or lowest value and using none of the values in the middle. Another style is acquiescence, where respondents tend to agree with the researcher/designer regardless of what they are asked. In an interesting use of hierarchical linear modeling, Johnson et al. (2005) identified associations between power distance and masculinity as predictors of extreme response style. Acquiescence was associated with several cultural dimensions including high uncertainty avoidance, high collectivism, high femininity, and high power distance. The higher a culture scored on these values, the stronger the acquiescent response pattern.

Another consideration in the usability process is whether to bring consumers to you (as the designer) or go to the consumers. For example, in some product testing, designers prefer to bring users into the companies or into a quiet and controlled setting, while other designers prefer taking their product into the users' setting for testing. There is no precise formula. Besides culture, the location for product testing is influenced by the development phase of the product (i.e., released product? prototype?) and the intent of the designer. In the aforementioned Piegorsch (2009) study, testing a loom in a controlled space may not have been effective in identifying usability problems because the loom is typically used outdoors and in plain sight of others who may be working or passing by. The work postures are likely to change during the weaving task because the worker will be interacting with others while weaving. However, testing a mobile phone might be appropriate for a quiet space under certain instances because mobile phones are designed to be used in a number of different contexts.

In summary, data elicitation is not easy to construct because the instrument has to be culturally compatible to the consumers who are the target groups. There are a number of other usability process issues that need to be considered when conducting product design processes. But, they are beyond the scope of this chapter.

14.4 CONCLUSIONS

Cultural ergonomics should be understood as a framework, and not as a recipe for design features. There are some factors with empirical backing that support cultural influences on usability, while others are not yet known and others may be over-generalizations. Researchers continue to explore cultural patterns and their relationship to design. Given the research to date, there have been attempts to isolate basic design features that may be helpful. These are available in the research literature and include the design of symbols and graphics, the expression of time and date, the use of colors, and product form and functionality. Companies with highly diverse target groups (e.g., gender, generation, nationality) must consider how the levels of culture interact to influence usability and preference. One way to resolve this complex design challenge is to offer customization of the project or to offer more than one design of the same product line.

Admittedly, it is difficult to write from a global perspective given that each author of this chapter has been socialized in more than one culture, including Western, Eastern, and predominantly European cultures. However, an attempt was made to be broad in our discussion of relevant concepts and guidelines to allow room for cultural customization based on researchers' and practitioners' intentions. Regardless of the controversies and levels of agreement, there is much evidence that designing for human variability offers an advantage over homogeneous product design characteristics. We offer here an opportunity to use a methodology that considers variability and inclusion as a basic tenet of practice, several case examples, methods that can facilitate culturability, and important differences to consider that abound in the research literature.

REFERENCES

Aryana, B., and S.J. Zafarmand. 2007. Glocal produce design: A sustainable solution for global companies in regional and/or local markets. International Association of Societies of Design Research IASDR 07, The Hong Kong Polytechnic University School of Design, November 12–15. Hong Kong.

Barber, W., and Badre, A. 1998. Culturability: The merging of culture and usability. Presented at the Conference on Human Factors and the Web, Basking Ridge, New Jersey: AT&T Labs. Online: http://research-kinasevych.ca/2010/05/barber-badre-1998-culturability-the-merging-of-culture-and-usability/ (accessed November 1, 2009).

Berdahl, J., and Anderson, C. 2005. Men, women, and leadership centrality in groups over time. *Group Dynamics: Theory, Research, and Practice* 9:45–47.

Betancourt, H., and Lopez, S. 1995. The study of culture, ethnicity, and race in American psychology. In *The Culture and Psychology Reader*, eds. N.R. Goldberger and J.B. Veroff, 87–107. New York: New York University Press.

Bevan, N. 2001. International standards for HCI and usability. *International Journal of Human Computer Studies* 55:533–52. Online: citeseerx.ist.psu (accessed February 14, 2010).

Borg, G. 1970. Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine* 2:92–98.

Chapanis, A. 1974. National and cultural variables in ergonomics. *Ergonomics* 17:153–75.

Cornwell, T., and Drennan, J. 2004. Cross-cultural/consumption research: Dealing with issues emerging from globalization and fragmentation. *Journal of Macromarketing* 24:108–21.

Green, E., Owen, J., and Pain, D. 1993. Introduction. In *Gendered by Design? Information Technology and Office Systems*, eds. E. Green, J. Owen, and D. Pain, 1–8. London: Taylor and Francis.

Gupta, A., and Ferguson, J. 1997. *Culture, Power, Place: Explorations in Critical Anthropology.* Durham, NC: Duke University Press.

Hall, E. 1966. *The Hidden Dimension.* New York: Anchor Books.

Hart, S., and Staveland, L. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Human Mental Workload*, eds. P.A. Hancock and N. Meshkati, 139–83. North-Holland: Elsevier Science.

Henwood, F. 1993. Establishing gender perspectives on information technology: Problems, issues and opportunities. In *Gendered by design? Information technology and office systems,* eds. E. Green, J. Owen and D. Pain, pp. 31–49. London: Taylor and Francis.

Hofstede, G. 1997. Cultures and organizations: Software of the mind. London: McGraw Hill.

Howe, N., and Strauss, W. 1997. *The Fourth Turning: What the Cycles of History Tell Us About America's Next Rendezvous with Destiny*. New York: Broadway Books.

Johnson, T., Kulesa, P., Cho, Y., and Shavitt, S. 2005. The relationship between culture and response styles: Evidence from 19 countries. *Journal of Cross-Cultural Psychology,* 36 (2): 264–77.

Lin, R., Sun, M.-X., Chang, Y.-P., Chan, Y.-C., Hsieh, Y.-C., and Wuang, Y.-C. 2007. Designing "culture" into modern product: A case study of cultural product design. In *Usability and Internationalization, Part I, HCII 2007, LNCS 4559*, ed. N. Aykin, 146–53. Berlin: Springer-Verlag.

McDermott, R., and Varenne, H. 1994. Culture "as" disability. *Anthropology & Education Quarterly* 26:324–48.

Moalosi, R., Popovic, V., Hudson, A., and Kumar, K. 2005. Integration of culture within Botswana product design. In *Proceedings 2005 International Design Congress*, National Yunlin University of Science and Technology-Yunlin, Taiwan.

Moalosi, R., Popovic, V. and Hickling-Hudson, A. 2007. Culture-oriented product design. International Association of Societies of Design Research. The Hong Kong Polytechnic University, 12th–15th November, 2007. Online: http://www.sd.polyu.edu.hk/iasdr/proceeding/papers/culture-orientated%20product%20design.pdf (accessed January 31, 2011).

Moggridge, B. 1993. Design by storytelling. *Applied Ergonomics* 24:1.

Nunnally, J., and Bernstein, I. 1994. *Psychometrics*, 3rd ed. New York: McGraw-Hill.

Piegorsch, K. 2009. An ergonomic bench for indigenous weavers. *Ergonomics in Design* 17:7–11.

Scholte, J. 2000. *Globalization: A Critical Introduction*. London: Macmillan.

Smith-Jackson, T.L., and Essuman-Johnson, A. 2002. Cultural ergonomics in Ghana, West Africa: A descriptive survey of industry and trade workers' interpretations of safety symbols. *International Journal of Occupational Safety and Ergonomics* 8:37–50.

Smith-Jackson, T.L., Headen, E., Thomas, C., and Faulkner, B. 2005. Cultural critical incidents in hazardous occupations: A preliminary exploration. In *Human Factors in Organizational Design and Management – VIII*, eds. P. Carayon, M. Robertson, B. Kleiner, and P.L.T. Hoonakker. pp. 479–84, Santa Monica, CA: IEA Press.

Smith-Jackson, T.L., Wogalter, M.S., and Quintela, Y. 2010. Safety climate and pesticide risk communication disparities in crop production by ethnicity. *Human Factors and Ergonomics in Manufacturing*, 20:511–25.

Swart, T., Molenbroek, J., Langeveld, L., van Brederode, M., and Brecht, J. 2009. Outdoor seating design to facilitate social interaction among older adults. *Ergonomics in Design* 17:4–6.

Talen, E. 2006. Design that enables diversity: The complications of a planning ideal. *Journal of Planning Literature* 20:233–49.

Tulgan, B. 2009. Generation Y defined: The new young workforce. Online: http://www.hrtools.com/insights/bruce_tulgan/generation_y_defined_the_new_young_workforce.aspx (accessed February 15, 2010).

Valsiner, J. 2001. *Culture & Psychology*. Thousand Oaks, CA: Sage.

VandenBos, G.R. 2007. Editor in Chief, *APA Dictionary of Psychology*. Washington, DC: American Psychological Association.

Veroff, J., and Goldberger, N. 1995. What's in a name? In *The Culture and Psychology Reader*, eds. N.R. Goldberger and J.B. Veroff, 3–21. New York: New York University Press.

Webster, J. 1993. Form the word processor to the microcomputer: Gender issues in the development of information technology in the office. In *Gendered by Design? Information Technology and Office Systems*, eds. E. Green, J. Owen, and D. Pain, p. 115. London: Taylor & Francis.

15 Affective Design and Consumer Response

Rosemary R. Seva and Martin G. Helander

CONTENTS

15.1 AFFECTIVE PRODUCTS

Not all products are able to induce a strong affect that can influence a consumer to make a purchase. Only products that highly involve customers in the purchase process are likely to elicit strong emotions, such as expensive and highly personalized items. Consumers usually take time and effort buying these products and consider several factors in decision making, including product semantics.

Product semantics, a phrase coined by Krippendorf and Butter, refers to the inherent meaning conveyed by a product (Demirbelek and Sener 2003). People buy a certain product or a certain brand because they want to express themselves. A product, therefore, tells a lot of things about the user. Bih (1992) gave some examples of products classified according to the meaning attached, namely,

- Television—functional and utilitarian
- Statues—religious or cultural
- Medals—personal achievements
- Mementos—memory aid
- Mobile phone—social exchange
- Travel—shared personal experience
- Antiques—personal values

In relation to this, Mono (1997) defined the four semantic functions of products: to describe, to express, to signal, and to identify. These semantic functions coincide with some of the classification of products presented by Bih (1992). Affect is a psychological response to the semiotic content of a product. Therefore, products such as clothes and personal effects with meanings attached to them are likely to arouse emotions.

Products can also be classified according to the factors that drive their development. Ulrich and Eppinger (2000) classified products into user driven or technology driven or a combination of the two. Technology-driven products are those that are bought by consumers because of their technology and their ability to accomplish a certain task. One typical example is the hard disk drive of the computer. Although these products need to be designed considering ergonomics and other aesthetic aspects, the main selling point of this product is its technical capability.

User-driven products, on the other hand, are products purchased by consumers because of their functionality and aesthetic aspects. Users interact with these products very often and they become quite personal. Owning these products gives a sense of pride and a "semantic purpose." An example is a wristwatch that is chosen by the user because of its style and uniqueness.

Combinations of these two extremes are the technology- and user-driven products that have a high degree of interaction with the users and at the same time are highly technological. A typical example is the mobile phone, which has become very personal to most users. Current designs of mobile phones allow more flexibility in terms of designing and personalizing it. At the same time, phone manufacturers are thinking of better ways to get ahead of their competitors by including more features in their product. Later designs of mobile phones include personal data assistant (PDA), camera, radio, and MP3 player. From this classification, only the user-driven technology and the combination of the two are likely to incite emotion from users or possible buyers of the product.

In marketing research, a consumer good is classified as convenience goods, shopping goods, and specialty goods (Tull and Kahle 1990). Convenience goods are easy to buy. Some examples include candies, a handkerchief, etc. Shopping goods require more effort on the part of the consumer in terms of travel and decision making. Specialty goods are typically more expensive and take significant effort to buy. Examples include perfume, cellular phones, and jewelry.

Another broad category of products is industrial goods, which include materials, fabricated parts, equipment, installations, and supplies. These are purchased by companies, and are not directly used by consumers.

In this classification, only consumer goods, particularly shopping and specialty goods, are likely to evoke feelings from the user or buyer, because they become involved with the product in looking for it and paying a significant price to acquire it.

15.2 MODELS OF CONSUMER DECISION MAKING

In analyzing the consumer decision-making process, Schiffman et al. (2001) enumerated four models, namely, (1) economic man model, (2) passive man model, (3) cognitive man model, and (4) emotional man model. These models are important in understanding the motivation for affective design and the theoretical foundations for decision making in the shopping context.

The economic man model assumes that a person makes rational decisions in an economic sense, and that they know all the possible alternatives in the market. This model has been criticized for being unrealistic because of its presumption of perfect knowledge. It is also not appropriate in the affective product design context because affect is not an economic variable.

The passive man model, on the other hand, depicts a person as someone who is submissive to the promotional efforts of marketing people. The main premise is that a person can easily be influenced by advertisements. It is thus implied that consumers will buy more of the product that is constantly promoted. This model has been criticized for portraying people as irrational and not analytical. Some consumers research potential products and decide depending on the information gathered. Information on affect is valuable since it includes important aspects of an existing situation.

The cognitive model of consumer decision making depicts the consumer as a thinking problem solver. The cognitive model focuses on the processes by which consumers seek and evaluate information about product brands and retail outlets. In this case, the consumer is seen as an information-processing system that forms preferences leading to purchase intentions. The preference formation strategy may be based on the input of other people, such as friends, experts, or relatives, who help consumers establish their preference (Schiffman et al. 2001).

Consumers have a limited capability to process and remember information. The concept of bounded rationality proposes that consumers cannot be rational in an economic sense, but try to make the best decisions given their information processing limitations. Consumers stop searching for product information if they think they already have sufficient information to make a decision. Most of the time, consumers use shortcut decision rules (called heuristics) to facilitate the decision-making process. Heuristics are also employed to cope with information overload (Schiffman et al. 2001).

Some common heuristics employed by consumers in decision making include the availability heuristic (Folkes 1988), scarcity choice heuristic, liking choice heuristic (Whittler 1994), judgment referral heuristic (Mattila 1998), and elimination by aspects (Tversky 1972). The availability heuristic is used by consumers because of memory limitations. Information that is readily available at the time of purchase influences their decisions. On the other hand, the scarcity choice heuristic is used when there is an impending increase in price if the item is not bought at a particular time. In this case, the consumer thinks that a good deal will be lost if one does not make a purchase. The liking choice heuristic is influenced by affect as it refers to the feeling of the consumer toward the seller. This heuristic is commonly used by consumers when the items available are not extremely differentiated. Judgment referral is a heuristic that depends on what other people said about the product. Since most consumers avoid cognitive effort when making decisions, they rely on the input of other people. Another simplifying heuristic is the elimination by aspect proposed by Tversky (1972). Products that do not conform to criteria formulated by the consumer are immediately eliminated using this heuristic. As such, the choice is eventually limited to only a few items. This heuristic prevents cognitive overload on the part of the consumer.

The last model of consumer decision making is based on emotion. In this model, consumer decision is based on deep feelings or emotions, such as joy, fear, love, hope, etc. Consumers buy products because their emotions are activated during the purchase process. Impulse buying is triggered by emotion and happens when consumers do not have enough time to think about the decision (Shiv and Fedorikhin 1999). However, it is not fair to say that decisions made using emotions are irrational, because some products are meant to satisfy people's emotions and are perfectly rational.

Moods are also important in consumer decision making, because they have significant influence when consumers shop. Barone, Miniard, and Romeo (2000) found that positive mood influences consumer evaluations of brand extensions. Specifically, positive mood enhances consumers' evaluation of brand extensions viewed as similar to a core brand evaluated favorably by consumers. Swinyard (1993) also discovered that mood interacts with consumer involvement in the purchasing process. Shoppers in a good mood have biased evaluations of products, because they want to preserve the good mood they experience.

The emotional model of consumer decision making asserts that some decisions are made because of strong emotions. The emotions are brought about by a number of things that also include the product itself. However, it is not known what product attributes trigger emotions and if the emotion is enough to form a purchase intention. Personal products that indicate the user's personality, can evoke more intense emotion. If a consumer goes to a shop where ten wristwatches of the same price are displayed, at the end of the day this shopper will buy only one particular watch. The decision was not based on price, utility, environment, or salesperson interaction, because these were constant for all ten designs. In this case, the design of the watch itself determined the decision of the shopper. Rather, the design could have activated some emotions that motivated one's decision.

15.3 EMOTION AND CONSUMER CHOICE

A consumer is faced with many choices when buying a product. As such, there is a need to form decision criteria to compare available options. These criteria can be complex or single criterion, such as a brand name, appeal, or design. The weighting of the criteria is influenced by emotion, and this entails giving emotional significance to choice criteria appropriate to a person's purchasing objectives. O'Shaughnessy (1987) enumerated six categories of criteria and discussed their emotion potential.

1. Technical criteria: The technical function of a product is the main reason for its existence. For example, a car functions to take a passenger from one place to another. A car can only be labeled as good if it is able to perform its core function satisfactorily. However, marketing people may include special features and describe their products to evoke emotions. Words like user-friendly and easily adjustable are used to suggest pleasure when using the product. Positive emotions are usually felt when the performance or feature of the product is better than expected and negative emotions when expectations are not satisfied.
2. Economic criteria: One of the most important criteria that consumers use is the price, because the money they have to pay represents a sacrifice for buying the product. Paying for the product dampens the enjoyment that it brings to the consumer (Brittan 1997). The maximum price of a product depends on its uniqueness, the social perception of the wisdom of paying the price, the perceived fairness of the price, and the store location. All these factors evoke emotion on the part of the consumer.
3. Legal criteria: Some buying criteria are decreed by others, hence the name legalistic criteria. When a husband shops using a list prepared by his wife, it can be stressful, because the buyer may not find the appropriate things to buy or may encounter budget problems. Such shopping experiences can evoke frustration.
4. Integrative criteria: Refer to the need of a person for social integration and integration with one's sense of identity. Integrative criteria involve social acceptance, self-identity, status, fashion, and personal integrity. Consumers think that they should buy products that will conform to the standards set by society and their own social milieu. Some people feel embarrassed if they do not conform to these standards and feel proud otherwise.
5. Adaptive criteria: Refer to the desire of the consumer to minimize risk related to the purchase. Risks can be financial, physical, social, performance, or hassle in having to return the product. Many products are not evaluated thoroughly before the purchase, and as a result, uncertainties arise. A high-risk purchase, such as a cheap product with an unknown brand may bring anxiety to the consumer. In order to avoid risks, consumers tend to rely on what others have to say, such as experts or friends. Most people opt to buy products of known brands or those that are endorsed in advertisements.
6. Intrinsic criteria: Refer to the characteristics of the product, such as its look, texture, smell, sound, etc. Products are bought to please the senses, and one reason for buying is enjoyment. Consumers sometimes make irrational decisions because they seek pleasure. Markets abound with food that is nutritious but lacking in good taste. For example, non-fat mayonnaise is available for people who would like to reduce their fat intake, however, only a few people buy this because they prefer to enjoy the good taste of real mayonnaise. This example shows that even though some choices can be beneficial in the long run, consumers elect to maximize short-term pleasurable benefits.

Intrinsic criteria, however, are molded through education and experience. A person will not appreciate something as good unless one knows its benefit. Works of art, for example, may not mean so much for a person who does not know the artist and how the artwork came about. It may also be shaped by culture that somehow dictates the criteria for beauty.

The appreciation of beauty has emotional implications. Aesthetics pervades in products we buy, such as cars, clothes, furniture, food, painting, music, etc. Novelty invokes the emotion of wonder that draws attention to the product (O'Shaughnessy 2003).

From the six criteria mentioned above, it can be established that emotions are incited by the environment, the situation, and the product characteristics. Aside from rational thinking, emotion is used by many people for guiding purchase decisions. Intrinsic criteria enforce the role of product characteristics in influencing consumers to buy a product.

15.4 AFFECTIVE DESIGN

Affect is a common experience that most people take for granted without realizing that it significantly influences their behavior. Experience of pain and pleasure shapes a person's outlook on quality of life (Larsen and Fredrickson 1999). It is also a significant source of human motivation and has a bearing on memory and thought processes (Westbrook and Oliver 1991). Many decisions are made on the basis of emotion rather than complex thinking and decision making, especially in the shopping context.

Emotions are compelling human experiences and designers can capitalize on this by conceptualizing emotion-engendering products that can capture consumers' interests. Fulton Suri (2005) highlighted "design experience" as a key influence in conceptualizing good designs. This entails knowing users' activities, thoughts, feelings, aspirations, goals, rituals, and values and translating them into a product that elicits positive emotional responses. Better designs are capable of provoking positive reactions from people, such as achievement, inspiration, and joy (Givechi and Velasquez 2004).

The interest in emotional response to product design is driven by its marketing benefits. Consumers are enticed to buy some products because emotions were activated during the purchase process. The product's "soft functionality," referring to its compliance with users' emotional needs, was cited by McDonagh, Bruseberg, and Haslam (2002) as a factor that affects product success in the market. Kansei engineering tries to incorporate customers' feelings into the design of the product by translating these feelings into design elements that are related to form and other sensory characteristics (Matsubara and Nagamachi 1997; Nagamachi 1995, 2002). Similarly, Jordan (1998) tried to determine the feelings of pleasure and displeasure associated with product use. He discovered that satisfaction in using a product is brought about not only by usability, but also by the emotions engendered by the product, such as excitement and pride.

Designers normally use their intuitive judgments when designing products. Creativity is believed to be innate and some people are gifted with the talent of conceptualizing visually pleasant forms. The application of scientific method to design was not deemed appropriate because artistry is the way to a good design. Coates (2003), however, did not completely adhere to this belief, asserting the need to measure consumer response to products and relate the response to product features. Such a method scientifically aligns design elements to consumers' aesthetic preferences. The use of scientific method in design has the benefit of optimizing the process by focusing efforts on a few significant aspects of the product.

The crucial role of product form in product success prompted some researchers to identify product characteristics that are related to customer satisfaction. Han and Hong (2003) investigated product characteristics that influence eight satisfaction dimensions in the use of audio/visual products. Attractiveness and overall satisfaction were included in the satisfaction dimensions, which were feelings of arousal, pleasantness, and contentment. Yun et al. (2003) conducted a related study where design features of cellular phones were correlated to the perceived satisfaction of users expressed in ten dimensions, namely, luxuriousness, simplicity, attractiveness, colorfulness, texture, granularity, harmoniousness, salience, ruggedness, and overall satisfaction. Customer satisfaction was distinguished by Cohen and Areni (1991) from emotion, defining it as an attitudinal post-purchase evaluation of the product and not a feeling state. Khalid and Helander (2004) built a framework for including affective customer needs in product design by asking customers' preferences of 15 product attributes of four devices. These three studies, however, did not necessarily consider emotional responses as a dependent variable. As such, it is not possible to know which product characteristics are responsible for positive or negative feelings of affect.

Norman (2003) pointed out the importance of considering the positive emotion evoked by a product because it may lead consumers to overlook the product's faults. A product that is beautiful can make people smile and may affect a person's purchase decision. Designing a good product also involves making it pleasurable and exciting to use. Pleasure is now considered by many to be more important than usability and is seen as an improvement in user-centered approaches in design

(Cayol and Bonhoure 2001). Marketers, nowadays, are interested in understanding the influence of affect in decision making and response to marketing variables (Barone, Miniard, and Romeo 2000; Garbarino and Edell 1997; Gorn, Goldberg, and Basu 1993; Westbrook 1987).

15.5 AFFECTIVE RESPONSES TO DESIGN

One challenge that designers face in integrating affect in design is quantifying the consumer's response. Emotion is difficult to define and even more difficult to measure. If decisions and actions must be predicted through statistical means, there is a need to devise a way to measure affect and integrate it in the analysis.

One way to measure the emotional experience of a person is to identify the emotion felt and its intensity through the use of rating scales and adjective checklists (Larsen and Fredrickson 1999). One methodological dilemma is to use a scale to measure emotion or to identify the types of emotions experienced. This is one reason why so many techniques have been devised to describe emotional experiences. Many techniques assume that participants can recall what they have felt in a certain situation and that they can assess the intensity of what they felt using a scale. It also implies that the participants are capable of identifying the types of emotions they felt and distinguish one from another.

The taxonomy of affect devised by Izard (1977), Russell and Pratt (1980) and Plutchik (1980) considered all emotions that can possibly be experienced in various situations. Richins (1997), however, inquired whether these classifications are relevant in the consumption experience. Some of the basic emotions are too strong to be felt by a shopper while looking for a product to buy. In a related study, it was found that advertising brings about low-intensity emotions that are limited in nature. Richins (1997), therefore, found it necessary to identify the emotions relevant to the different stages of consumption experience.

Richins (1997) developed the consumption emotion set (CES) obtained from the analysis of three consumption situations, namely, automobile, recreational, and sentimental. There were seventeen sets of emotion: anger, discontent, worry, sadness, fear, shame, envy, loneliness, romantic love, love, peacefulness, contentment, optimism, joy, excitement, surprise, and others. Westbrook (1987), in a related study, observed the experience of joy in the evaluation of a vehicle. However, this emotion set was constructed considering all facets of consumption, from anticipation to actual use of the product. This list is wide in scope and may not be very relevant in the context of product selection. Moreover, non-valenced emotions, such as interest and surprise, were not included in the analysis.

Mano and Oliver (1993) made a similar study but considered only the post-consumption experience. They identified three aspects of post-consumption experience: evaluations, feelings, and satisfaction. They proposed that satisfaction is closely related to affect, but affect precedes satisfaction. Their study sought to validate the two dimensions of affect proposed by Russell and Pratt (1980), namely, pleasure and arousal. The results suggest that the dimensions of affect proposed by Russell are tenable in the consumption experience, but a three-factor solution included positive affect, negative affect, and low arousal and warmth. These results coincide with the findings of Westbrook (1987) that positive and negative affect influence consumption experience. Furthermore, Havlena and Holbrook (1986) were also able to confirm that Russell and Mehrabian's (1977) pleasure, arousal, and dominance (PAD) paradigm is consistent with consumption experience. It is worth noting that the study of Havlena and Holbrook addressed only post-purchase experience.

Desmet (2003), on the other hand, classified emotional responses into five categories, namely, instrumental, aesthetic, social, surprise, and interest. Instrumental emotion refers to the perception that the product can help the user achieve their objectives, whereas aesthetic emotion pertains to the capability of the product to appeal to the consumers. Social emotion results from the use of products that adhere to socially determined standards. Surprise emotion is brought about by the consumer's perception that the design is new, while interest emotion is elicited by the combination of challenge and promise (Tan 2000). In comparison with the work of other researchers, Desmet's work is limited in the sense that he only classified emotions and did not enumerate them. His study could have been extended by identifying emotions that may be classified under each heading through the use of factor analysis. However, his classification brought a new way of looking at the classification of emotion as not only positive or negative or pleasure and arousal.

Considering the limitations of previous studies, Seva, Duh, and Helander (2005) developed the pre-purchase emotion set (PES) in order to capture the consumer's affect before they actually buy the product. The pre-purchase stage refers to the time when the consumer is looking for a product to buy that is already determined beforehand. Post-purchase stage, on the other hand, refers to the actual consumption or use of the product. During the pre-purchase stage, the emotion felt for the product can be a deciding factor in making a purchase. As such, a method for measuring emotions should be devised to investigate the capabilities of products to engender emotion even at the prototype stage. The self-report of affect is one of the methods that can reliably do this, but the checklists currently available in the literature enumerate numerous emotions that are irrelevant in the context.

The PES was gathered from a field study of shoppers in Singapore who recently made a purchase of clothing, a watch, and electronic products (Seva, Duh, and Helander 2005). The list of affect was gathered through a questionnaire that presented three scenarios that the consumer may have experienced while shopping, namely, purchase an item of clothing, electronic product, or a watch. The questions for each scenario sought to identify the affect experienced while examining the products they bought or chose from. The consumers were incited to think of the words on their own at first in order to generate a set of affect descriptors independently. However, a list of emotions was also provided to assist the consumer in identifying pre-purchase affect that they may have missed in the process. The emotions in this list were taken from the CES gathered by Richins (1997) in her study of consumption-related affect.

Although pre-purchase affect was sought to be identified in this process, a post-hoc survey was utilized because it is rational to think that all pre-purchase affect would have been experienced only at the end of the shopping activity. If the interview had been done before the end of the shopping activity and the consumer had not made a decision, it is possible that some pre-purchase affect may have been missed by the interviewer. Moreover, although it is a post-hoc survey, the survey was done immediately after the shopping activity; thus, the consumer's memory of the experience was still fresh in their mind.

An initial list of pre-purchase affect was identified from field studies. A total of 94 emotions were initially gathered which was judged too many to be subjected to further analysis. As such, these words were reduced in number by considering the frequency of use in daily context. The streamlined affective words were reduced to 23 after considering frequency of use. Only words that were used "often" and "always" by at least 40% of the respondents were considered for further analysis. Table 15.1 reflects the final list of pre-purchase affect, labeled the PES.

The set of pre-purchase emotions is applicable to the identification and measurement emotions experienced by the consumer when evaluating a product. The emotion set obtained by other researchers did not particularly consider the pre-purchase context and as such, some emotions may not be relevant. Richins (1997), for example, proposed the CES, which was derived from the analysis of three consumption situations, namely, automobile, recreational, and sentimental. However, this emotion set was constructed considering all facets of consumption from anticipation to actual use of the product.

TABLE 15.1
Pre-purchase Emotion Set

1. Amazed	7. Enthusiastic	13. Hopeful
2. Cheerful	8. Excited	14. Interested
3. Concerned	9. Fulfilled	15. Joyful
4. Contented	10. Glad	16. Pleased
5. Delighted	11. Good	17. Surprised
6. Encouraged	12. Happy	18. Thrilled

15.6 CONCLUSION

One issue in affective design is its domain of application. It was earlier argued that this method is applicable to high-involvement products. The concept of high involvement, however, is dubitable and needs to be operationally defined. There are numerous products in the market, but only a handful can be subjects of affective design. These are products that are expensive and expressive. They enable users to show uniqueness in their style or personality, setting them apart from the rest. The prospect of owning such a product generates a variety of emotions that are not applicable when confronted with highly standardized products. In essence, deep-seated desires of users for individuality, pleasure, and aesthetics cause emotion in product evaluation.

The use of affect as a means of conceptualizing and evaluating designs required the development of a measurement system that is appropriate for the context. Users encounter products every day and make decisions that are sometimes emotionally driven. Emotions that users experience when they inspect and evaluate products are called pre-purchase affect and consist of a unique set of emotions. The pre-purchase context was differentiated from post-purchase because this situation is characterized by limited time and consumers' reliance on instincts and impressions when making a purchase. They evaluate products that they find attractive and it is at this point that pre-purchase emotion is elicited.

The PES included eighteen emotions that were predominantly positive compared to other emotion sets found in the literature, such as those developed by Russell and Pratt (1980) and Richins (1997). The eighteen components of the PES may be used in subjective measurement of emotional intensities in studies involving affective design of "high-involvement" products.

REFERENCES

Barone, M.J., Miniard, P.W., and Romeo, J.B. 2000. The influence of positive mood on brand extension evaluations. *Journal of Consumer Research* 26:386–400.

Bih, H. 1992. The meaning of objects in environmental transitions: Experiences of Chinese students in the United States. *Journal of Experimental Psychology* 12:135–47.

Brittan, D. 1997. Spending more and enjoying it less. *Technology Review* 10:12–13.

Cayol, A., and Bonhoure, P. 2001. Future design: A search for the user's pleasure. In *Proceedings of the International Conference on Affective Human Factors Design*, eds. M. Helander, H. Khalid, and M. Tham, London: Asean Academic Press.

Coates, D. 2003. *Watches Tell More than Time: Product Design, Information and the Quest for Elegance*. London: McGraw-Hill.

Cohen, J., and Areni, C. 1991. Affect and consumer behavior. In *Handbook of Consumer Behavior*, eds. T. Robertson and H. Kassarjan, 188–240. Englewood Cliffs, NJ: Prentice-Hall.

Demirbelek, O., and Sener, B. 2003. Product design, semantics and emotional response. *Ergonomics* 46:1346–60.

Desmet, P.M.A. 2003. A multilayered model of product emotions. *The Design Journal* 6:4–13.

Folkes, V. 1988. The availability heuristic and perceived risk. *Journal of Consumer Research* 15 (1): 13–23.

Fulton Suri, J., and IDEO. 2005. *Thoughtless Acts*. San Francisco: Chronicle Books.

Garbarino, E.C., and Edell, J.A. 1997. Cognitive effort, affect and choice. *Journal of Consumer Research* 24:147–58.

Givechi, R., and Velasquez, V. 2004. Positive space. In *Design and Emotion: The Experience of Everyday Things*, eds. D. McDonagh, P. Hekkert, J. Van Erp, and D. Gyi, 43–47. London: Taylor & Francis.

Gorn, G.J., Goldberg, M.E., and Basu, K. 1993. Mood, awareness, and product evaluation. *Journal of Consumer Psychology* 2:237–56.

Han, S.H., and Hong, S.W. 2003. A systematic approach for coupling user satisfaction with product design. *Ergonomics* 46 (13/14): 1441–61.

Havlena, W.J., and Holbrook, M.B. 1986. The varieties of consumption experience: Comparing two typologies of emotion in consumer behavior. *Journal of Consumer Research* 13:394–404.

Izard, C. 1977. *Human Emotions*. New York: Plenum Press.

Jordan, P.W. 1998. Human factors for pleasure in product use. *Applied Ergonomics* 29:25–33.

Khalid, H., and Helander, M. 2004. A framework for affective customer needs in product design. *Theoretical Issues in Ergonomic Science* 5:4–15.

Larsen, R., and Fredrickson, B. 1999. Measurement issues in emotion research. In *Well-being: The Foundations of Hedonic Psychology*, eds. D. Kahneman, E. Diener, and N. Schwarz, 40–60. New York: Russel Sage Foundation.

Mano, H., and Oliver, R.L. 1993. Assessing the dimensionality and structure of the consumption experience: Evaluation, feeling, and satisfaction. *Journal of Consumer Research* 20:451–66.

Matsubara, Y., and Nagamachi, M. 1997. Hybrid Kansei engineering system and design support. *International Journal of Industrial Ergonomics* 19:81–92.

Mattila, A. 1998. An examination of consumers' use of heuristic cues in making satisfaction judgments. *Psychology and Marketing* 15 (5): 477–501.

McDonagh, D., Bruseberg, A., and Haslam, C. 2002. Visual product evaluation: Exploring users' emotional relationships with products. *Applied Ergonomics* 33:231–40.

Mono, R. 1997. *Design for Product Understanding*. Stockholm: Liber.

Nagamachi, M. 1995. Kansei engineering: A new ergonomic consumer-oriented technology for product development. *International Journal of Industrial Ergonomics* 15:3–11.

———. 2002. Kansei engineering as a powerful consumer-oriented technology for product development. *Applied Ergonomics* 33:289–94.

Norman, D. 2003. *Emotional Design: Why We Love (or Hate) Everyday Things*. New York: Basic Books.

O'Shaughnessy, J. 1987. *Why People Buy?* New York: Oxford University Press.

Plutchik, R. 1980. *Emotion: A Psychoevolutionary Synthesis*. New York: Harper and Row.

Richins, M.L. 1997. Measuring emotions in the consumption experience. *Journal of Consumer Research* 24:127–46.

Russell, J.A., and Mehrabian, A. 1977. Evidence for a three-factor theory of emotions. *Journal of Research in Personality* 11:273–94.

Russell, J.A., and Pratt, G. 1980. A description of the affective quality attributed to environments. *Journal of Personality and Social Psychology* 38:311–22.

Schiffman, L., Bednall, D., Cowley, E., O'Cass, A., Watson, J., and Kanuk, L. 2001. *Consumer Behavior*, 2nd ed. Australia: Pearson Education Australia.

Seva, R.R., Duh, H., and Helander, M. 2005. Development of a Conceptual Model of Product Emotion in the Pre-Purchase Context. Paper read at 11th International Conference on Human-Computer Interaction, Las Vegas, NV.

Shiv, B., and Fedorikhin, A. 1999. Heart and mind in conflict: The interplay of affect and cognition in consumer decision making. *Journal of Consumer Research* 26:278–92.

Swinyard, W.R. 1993. The effects of mood, involvement, and quality of store experience on shopping intentions. *Journal of Consumer Research* 20:271–80.

Tan, E.S. 2000. Emotion, art, and the humanities. In *Handbook of Emotions*, eds. M. Lewis and J.M. Haviland-Jones, 116–136. New York: Guilford Press.

Tull, D.S., and Kahle, L.R. 1990. *Marketing Management*. New York: Maxwell Macmillan.

Tversky, A. 1972. Elimination by aspects: A theory of choice. *Psychological Review* 79 (4): 281–99.

Ulrich, K.T., and Eppinger, S.D. 2000. *Product Design and Development*. New York: McGraw Hill.

Westbrook, R.A. 1987. Product/consumption-based affective responses and postpurchase processes. *Journal of Marketing Research* 24:258–70.

Westbrook, R.A., and Oliver, R.L. 1991. The dimensionality of consumption emotion patterns and consumer satisfaction. *Journal of Marketing Research* 18:84–91.

Whittler, T.E. 1994. Eliciting consumer choice heuristics: Sales representative's persuasion strategies. *The Journal of Personal Selling & Sales Management* 14 (4): 41–52.

Yun, M.H., Han, S.H., Hong, S.W., and Kim, J. 2003. Incorporating user satisfaction into the look-and-feel of mobile phone design. *Ergonomics* 46:1423–40.

16 Universal Design: Empathy and Affinity

George Edward Torrens

CONTENTS

16.1 INTRODUCTION

Why is it important for a designer to realize products and services for people who are elderly and/or disabled? The answer to this question may be provided by the author's own decision to work in this field. As a young designer in the 1980s, he wanted to make a difference to the quality of life of those in his society. On review of areas within which one could work, it was clear that medical or rehabilitation technology/assistive technology (RT/AT) product design would make the greatest impact on the target user's quality of life. Papanek (1974) advocated these areas as ones in which designers should aspire to work; he was many years ahead of the design establishment. From a societal viewpoint, using technology to enable people to be more independent and engage with society increases the potential help that finite resources can provide within a provision of care. It also facilitates the empowerment of an individual, enhancing their personal esteem, and supporting well-being. Over the last 20 years, the author has designed enabling products for people who are elderly and those who have some form of impairment.

16.1.1 Definitions Relating to Function and Disability

It may be worthwhile, at this point, defining impairment, disability, and handicap. Within the index of USERfit, Poulson et al. (1996) defined the three terms as

- Impairment: A loss or abnormality of psychological, physiological or anatomical structure or function.
- Disability: A restriction or lack (resulting from impairment) of the ability to perform an activity in the manner or within the range considered normal for a human being.
- Handicap: A disadvantage for a given individual, resulting from an impairment or disability, which limits the fulfilment of a role that is normal (depending on age, sex and social and cultural factors) for that individual. (*sic*)

The World Health Organization (WHO) has now redefined its method of classification into a more comprehensive, but complex system of classification. The International Classification of Functioning, Disability and Health (ICF) uses three separate health and health-related domains within which detailed classification is defined. The reason for the change to a more complex definition may be, in part, indicated through the following quote from the WHO website:

> Disability is not something that only happens to a minority of humanity. The ICF thus 'mainstreams' the experience of disability and recognises it as a universal human experience. (WHO 2010)

It would seem that the WHO is trying to remodel both the philosophy and terminology they use to help facilitate a more inclusive perception of people with an impairment or who may be elderly. The definitions stated in USERfit are those defined by the WHO from 1980; while now superseded, they offer a simplified introduction to the basic terminology used within this field of design.

In this chapter, strategies and methods are discussed by which designers may work viably and effectively in this challenging, yet rewarding field of product design. The focus of the information given will be around human-scale product design; however, most of the strategies and methods advocated are applicable to interior, architecture, and engineering design. The main discussion and examples will be around more severely impaired people, to highlight the efficacy of the research methods and design processes advocated. The same methods and processes may be applied to mainstream product design.

16.1.2 Definitions Relating to Design

The suggested ways of working and the examples provided are from the context of health and social care given within the UK. Additional comments may be given to highlight that the support systems and financial structures of other countries will affect how the suggested methods may be applied. The overarching principles within which these strategies and design methods are used are that they are both user centered (centric), and evidence-based decision making. Based on the author's experience, the final outcome is dependent on the quality of the information used to make design decisions.

Before explaining further about the specific demands and challenges facing designers, a working definition is required of the terms product designer, industrial designer, and universal design. The definition used for many years by the author with undergraduate students is given as

> An industrial designer produces the social and cultural functionality of a product within the constraints of manufacture and cost.

This definition clearly places the responsibility for the realization of desirability and or acceptance of a product by the stakeholders and target user onto the industrial designer. The constraints within which a product design may be realized include "fitness for purpose" and applies to the more complete product design specification (PDS). The PDS includes safety and industry standards alongside other constraints such as sustainability of the design.

The term universal design has been defined by Christophersen and Norske stats husbank (2002) as

> The Design of products and environments to be usable by all people, to the greatest extent possible, without adaption or specialized design (*sic*).

In addition, there are seven principles promoted by Christophersen, together with the definition of inclusive design; they are

1. Equitable use
2. Flexibility in use
3. Simple and intuitive use
4. Perceptible information
5. Tolerance for error
6. Low physical effort
7. Size and space for approach and use

Inclusive design is predominantly used within the UK to describe similar aspirations for the values underpinning a chosen design process. Internationally, there are many other titles given to this field of new product development (NPD): design for all; transgenerational design; design for the third age; and barrier-free design.

Now that definitions are in place within which the principles described may be applied, attention should be turned to the strategies and design tools available for use within this field, highlighting those that the author has found to provide effective results and to be most cost effective. Efficacy is often considered within healthcare and for a designer or team to provide metrics and evidence of efficacy of the new product or service is vital for success in this conservative market. These tools are applied within an activity pattern constrained by time and resources, as shown in Figure 16.1. Although only one route for an iterative cycle has been shown, reflection and revisiting will happen throughout the process. The number of iterative cycles that may be undertaken is constrained by time and resources.

16.2 KNOW YOUR MARKET: SOME OF THE CHALLENGES

The author's experience is that the quality of information available to a designer will have a direct influence on the quality of decisions and subsequent design outcomes produced, no matter how thorough and rigorous a design process may be applied. To paraphrase a commonly used statement within design circles: the quality of the information will lead to the design of the "right" thing. The latter half of this chapter will exemplify how to design the thing "right."

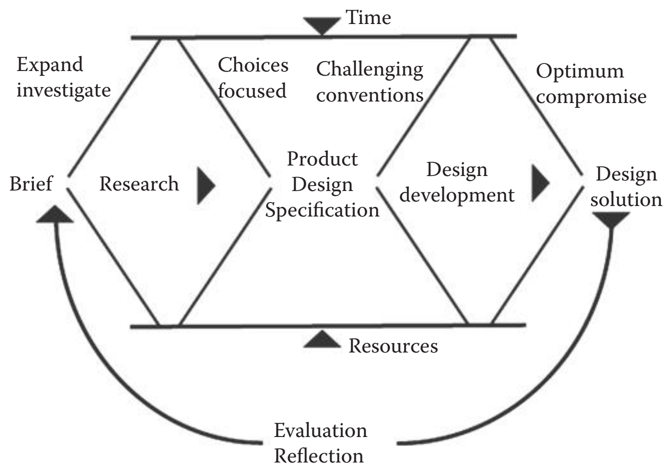


FIGURE 16.1 The double diamond of research and design activity within an NPD; constrained by time and resources.

16.2.1 Market Size and Implications for a New Product Development

As a starting point for any NPD, a designer must know the size and characteristics of their target market; these will influence the choice of manufacturing processes and materials constraints. For example, if a one-off customized seat unit is produced for an individual, vacuum forming of polymer sheet and hand finishing may be used; cutlery for people with a weak grip and limited dexterity, which is a much larger market, would require large batch quantity production methods such as steel pressing and polymer injection molding. The size of a target market can be gained from a number of sources: social science and ethnographic academic surveys; charitable support groups; market research surveys; and government census.

UK statistics from the Office for National Statistics (OSN) indicate that the population is getting older, with the proportion of the population over the age of 65 being more than 14% by 2011 (Her Majesty's Government 2010a). The current population has risen to over 60 million. In the mid 1990s, Sandhu and Wood reported that the proportion of people within European countries who are registered as disabled is approximately 11% of the total population (Sandhu and Wood 1990). Figure 16.2 shows the proportion of adults and children in 2007 that were registered as disabled in the UK. The chart was compiled from data available from the OSN (Her Majesty's Government 2010b, 2010c) and the Office for Disability Issues (Her Majesty's Government 2010d). These current figures indicate that the percentage of the population who have a recognized disability is now over 16% of the population. However, based on part of the European statistics collated by Sandhu and Wood, the breakdown of different groups within the UK population shows that most target markets are "niche." Although the target end users may be potentially in the hundred thousands, they are spread across the UK.

What must be kept in mind is that population demographics change, often rapidly. Regular updates of source data are vital to ensuring that the optimum information relating to a population is available against which a target user is matched.

16.2.2 Implications of Market Characteristics for a New Product Development

The allure for companies to exploit this large proportion of their market is offset by the challenges faced. The utopian ideals of the seven principles of universal design are difficult to implement. The RT/AT market is fragmented, with people having a wide range of very individual needs. While most people in this target market have common human aspirations to engage with everyday activities of

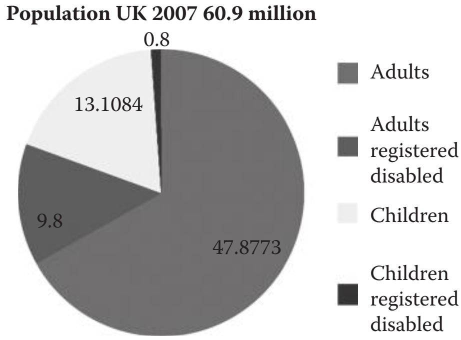


FIGURE 16.2 The prevalence of adults and children within the UK that are registered with a disability. (From Her Majesty's' Government 2010b; 2010c; 2010d.)

daily living (ADLs), their needs for physical or cognitive support from technology are very specific and wide ranging. The resulting niche markets often do not provide a viable return on the investment required to effectively undertake research and development of new RT/AT products. There may also be a perceived higher risk of litigation with possible unforeseen consequences of a new product in this marketplace, due to the end user/consumer's already vulnerable physical or cognitive state.

There is the added complexity of state or charitable support that may augment any funds that the individual or family may have, in order to purchase and access the product. Multiple stakeholders, who influence the purchasing decision, are often healthcare professionals or state budget holders. These supporting professionals, who are also advocates of the end user of the product, have demanding measures that the product has to attain before they will agree to release funds. New product suppliers may also have to be registered with the state or non-government organization (NGO) involved before their product may be purchased.

Characterization of the target market and the context within which products or services will be purchased may be considered as user, task, and environment (UTE) (see Figure 16.3). The example shown is of a "UTE mind-map" of the factors concerning the redesign of a powered wheelchair for a young woman with cerebral palsy.

Some of the challenges faced by new product developers have been detailed. Strategies and methods will now be described that enable designers to provide viable new products for this market. These processes may be considered to be just good design practice. They apply principles from human factors and ergonomics; address specific medical constraints for that associated condition; and satisfy the end users aspirations that may be in the form of desires for, or acceptance of, the product design.

16.3 KNOW YOUR USER: WAYS OF GAINING EMPATHY AND AN AFFINITY

This section will direct the reader toward resources that will enable a designer to populate the contextual landscape, shown in Figure 16.3. It will also describe how able-bodied designers can gain some empathy with their end user along with an affinity with their more subtle emotional needs, values, and aspirations.

16.3.1 Identifying Your Target User

It has been identified that a good working knowledge of the context within which purchasing decisions are made, as well as market size are required. While a literature review is a good starting point, identifying the associated medical definition of a target users' condition will enable a designer to gain some insight into the generic issues associated with it; which will then focus the

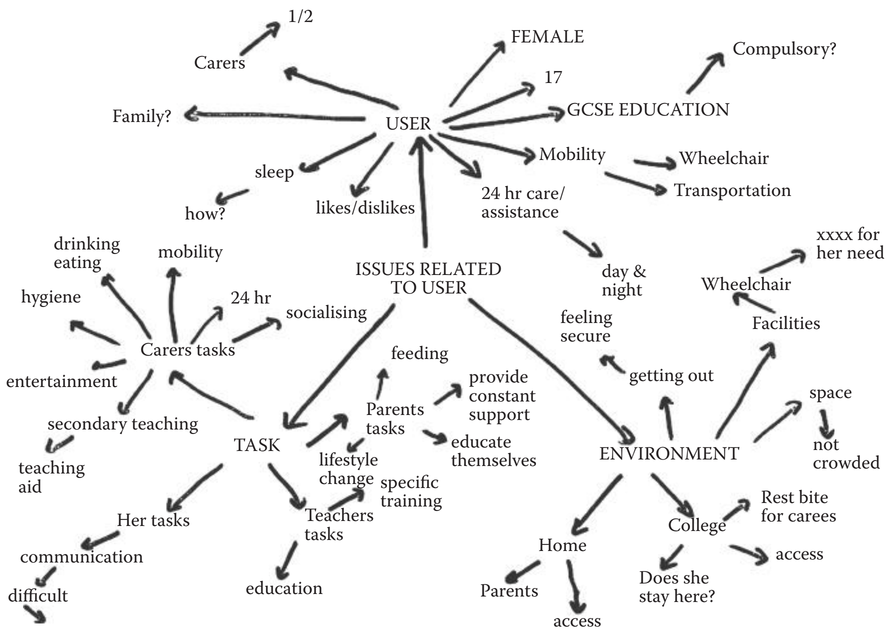


FIGURE 16.3 A mind map of the relationship between the user, task, and environment within the context of daily living activities of a wheelchair user. (From Allen et al., *Post-graduate and Undergraduate Exercise, Universal and Inclusive Design Module*. Loughborough Design School, Loughborough, 2000a.)

proposed research questions that drive a literature review. In the UK, there are associated support groups alongside defined medical conditions. The medical diagnosis and care regimes published in healthcare journals; characterization of the condition and associated information produced by support groups provides good background knowledge to the functional and physiological requirements of this target market. There may be associated medical conditions that present themselves within the end user as a compound impairment or disability. The detail within the information about a given medical condition also provides an awareness of the liability implications when considering product usage.

For example, a relatively large population of those registered in the UK as disabled with upper limb impairment, limited grip, or mobility have a form of arthritis. Understanding the characteristics of the condition, whether rheumatoid or osteoarthritis for example, will affect the final design. Each condition has a particular profile or persona associated with it. In the UK, osteoarthritis is often associated with older people, over 65 years old; with a larger proportion being female; and wear related. Rheumatoid arthritis affects a much wider age range, even children, and is characterized by episodic inflammation of the joints. The former will result in physically "stiff" joints; the later in "loose" joints. The optimum grip and associated characteristics of the product will be different for each condition, i.e., the optimum handle shape and covering material will be different. The challenge of widening the market for a niche market product will be addressed at the end of this chapter.

Defining a target market via the medical condition does enable world-wide cross-referencing; many of the associated support groups have equivalent organizations to those in the UK; and government statistical surveys may have equivalent data to those provided by the National Statistics Office (NSO).

16.3.2 Empathic Modeling of Your End User

Once focused on a target market and the related medical condition is identified, it will be possible to define the associated lifestyle and user characteristics of people within the target market. Gaining an affinity with the emotional needs and aspirations of a target user is then possible from the defined age, gender, and lifestyle. Methods by which a designer or team may gain empathy with some of the constraints on ADL are

- Predictive modeling
- Empathic modeling (replicating the physical elements of a medical condition)
- Mixed methods research
- Product/cultural probes
- Product champion

16.3.2.1 Predictive Modeling

Predictive modeling is applying existing knowledge about a target UTE, accessed through both generic and specific databases and design guides.

There are many such modeling databases that often include descriptions of research methods by which the data may be updated. Paper-based tools and databases include USERfit (Poulson et al. 1996) and Inclusive guidelines (Keates and Clarkson 2003). Computer-based predictive modeling has also been developed to enable more intuitive use. The Inclusive Design Tool Kit (Engineering Design Centre 2010), an internet database and methods guide is an intermediate to the software-based analysis tools shown in USERfit. Generic anthropometric databases, such as PEOPLEsize (Open Ergonomics 2000), support specific guidelines and tools. Software tools such as SAMMIE (Loughborough University 2010) provide physical ergonomics-based data, mainly for spatial accessibility and usability, the specification for which is imported into the software. HADRIAN (Porter et al. 2004) is an advance on the anthropometric-based design tools and databases such that it integrates the best of these elements. The software provides an information-rich interface for performance information collected from real people with defined medical conditions. Other chapters in this book provide more in-depth detail about SAMMIE and HADRIAN.

While these databases provide a very useful starting point to gain empathy with a target user, they are limited in the number of components they capture. An advantage that systems such as HADRIAN have is that they enable a cost-effective way for designers to match a target market with a clear population size and associated characteristics envelope.

16.3.2.2 Empathic Modeling

Empathic modeling is a well-used method through which designers can gain some experience of the constraints of a defined medical condition that manifests itself in a form of impairment. There are a number of proprietary "suits," such as the Third Age suit (Ergonomics and Safety Research Institute 2010) that can be manipulated to restrict movement, sight, or hearing. A low cost way in which designers can replicate such impairments through the use of hockey goalkeeper's protective equipment and modification of protective goggles has been documented by the author (Torrens 2000) (see Figure 16.4). This form of empathic modeling can also be used to gain insight into the role of carers and the emotional and physical demands on them during ADL.

Limitations for this way of gaining empathy with the end user are that the designer will not have the same emotional affinity or the insight into the aspirations of someone who has a long-term impairment or disability. The life perspective of someone born without an arm will be different from someone who has multiple sclerosis (a degenerative neuromuscular disease); and, different again to someone who has a broken leg. Each will want something different in terms of aesthetics and usability from a product that would provide a similar function.

Affinity with your end user, aligning with their emotional aspirations and values, is critical for a product designer to effectively provide the basis for product desirability or acceptance. This affinity may be considered to be a form of empathic modeling; it can be achieved through a number of strategies and methods that shortcut the need for extensive market or social sciences-based research.

FIGURE 16.4 A low-cost method of producing defined physical impairments to gain empathy with the end user.

One of the main objectives when collecting information from this target market is getting to know the current coping strategies associated with the product or service used by the end user; this is vital as it enhances the designer's awareness of the end user's decision making within a task performance.

Where possible, the most direct and information-rich way for a designer to understand their target user is to be within the end user's environment; observing, or watching, the tasks associated with the product or service being performed. From the author's experience, issues of lifestyle, cultural background, personal preferences of product, "taste," coping strategies, and emotional response to the activity are all intuitively noted. These images and scenes are recreated in the designer's mind when they are making design decisions about options within the proposed product or service. The intuitive practice of a designer may be more formally replicated through the use of mixed methods.

16.3.2.3 Mixed Methods Research

Mixed research methods provide a more comprehensive set of data on which to make design decisions. This method is a combination of qualitative research strategies complementing quantitative research activities, which together provide a more complete body of valuable data.

Formal research methods of observation and interview have been found to offer the most cost-effective "snap-shot" of the needs and aspirations of the end user. Task analysis, alongside interview, will provide the designer with much of the information required to gain enough insight to propose a design solution. The observation may be remotely from a video tape or key moments in a task recorded via photographs or even annotated stick figures. Teleconferencing, email, or social chat software, such as Skype, may be used to discuss issues. It should be noted that ethical use of social networks as a focus for research is an up and coming issue, as it has not been rigorously "policed"; being such a recent phenomenon.

16.3.2.4 Product/Cultural Probes

Product/cultural probes have been used successfully by a number of researchers eliciting information from individuals and groups over a longer time period (see Figure 16.5). Probes often consist of a diary that may be recorded in a number media. Written, drawn, photographic, and video-recorded evidence provides the NPD team with information-rich evidence into the daily living activities of individuals or social groups. It may also contain activities, tasks, or questionnaires to be filled in periodically by the participants. This form of ethnographic inquiry is less intrusive than a researcher being a "fly on the wall"; however, it would require a pilot study to ensure the balance

FIGURE 16.5 Product/cultural probes ready to go out to special needs schools; they contain a camera, directed drawing activities, and a short questionnaire.

between media recording formats, tasks, and questions was appropriate and viable to obtain from the target user group. Supporting site visits by designers (when participants are not at the location) are essential as they help them construct and better interpret the probes. These visits will also enhance the understanding of the environment in which their product will be used, without needing to gain ethical approval to meet with participants directly.

Based on the author's experience, a combination of physical characterization and past experience are part of the cost-effective snap-shot. Physical characterization is in the form of specific anthropometric dimensions related to the product and stature (as a reference measure; grip strength; and, some range of motion [ROM] measurements). A screening questionnaire can also lead to gaining more information about the participant's past experience of the product or service and define their associated medical condition.

16.3.2.5 Product "Champion"

Choosing a product representative, or "champion," has been found to be an effective way of identifying most of the issues relating to social and cultural functionality. It is critical that the chosen individual matches and reflects the larger population as closely as possible. The profile of the individual should match the defined medical condition, gender, and age. The socio-economic background has been found to be less important; the impairment and resulting disability has often inhibited the persona and lifestyle of the individual. The choice of product champion may be limited, due to the small market size, locally, nationally, and internationally. The value judgment of the appropriateness of an individual to be the product champion against accessibility, in terms of time and distance, has to be made by the designer or team. From the author's experience, it is better to have a local product champion and be aware that the individual's opinions may be skewed due to age, gender, or lifestyle.

16.3.3 Stakeholders

When investigating the professional characteristics and opinions of other fund holders and stakeholders, a group participatory approach is required. This group is influential in the purchase decision making, particularly in the UK where care service provision is predominantly provided by the Government.

16.3.3.1 Grounded Theory

A grounded theory approach (Creswell 2009) is a participatory approach to gaining consensus of opinion within a group of experts. In this field, the experts may be consultant surgeons, general practitioners, physiotherapists, occupational therapists, speech therapists, bioengineers, social workers, NGOs, and charitable budget holders. Each group will have a different perspective on the balance of the PDS and realized product. A derivative of grounded theory is the Delphi method (Cohen, Mannion, and Morrison 2007). This method involves remote communication between the research operator and individual experts, via questionnaire and given tasks, to arrive at a consensus achieved in grounded theory. This method enables the closest approximation of a face-to-face discussion with multiple participants without using a focus group strategy (Morgan 1997; Langford and McDonagh 2003).

16.3.3.2 Focus Group

In the author's experience, focus groups are both time and resource consuming and difficult to manage for the quality and quantity of data obtained. Additional factors include the vulnerable nature of the users involved and the increased opportunity for bias due to the involvement of carers.

16.3.3.3 Participatory Research

Participatory research instills a sense of ownership in the end user and stakeholders. It empowers end users to be more outspoken about their needs and aspirations. Involving all parties at an early stage enables a designer to cost-effectively recruit participants and support for the longer-term design and evaluation of a new product. The term "mixed research methods" advocated in this chapter are a collection of methods where quantitative (grip strength, anthropometry) and qualitative data (opinions, comments, emotional responses) are collected from within the context of a "happening" or phenomenon (e.g., a design process). Case study is a good example of the application of mixed methods research within an NPD. It is considered by many to be primarily a qualitative recording of an "instance" (observed activities); however, it can have other quantitative metrics, such as task performance outcomes and physical measurements (such as increase the co-efficient of friction at a handle interface).

16.3.4 Ethics

Ethical protocols should be followed with any design research inquiry. There are a number of detailed references that provide guidance on the ways in which both participant and research operators can be safe guarded, and provide templates for an ethical approach to mixed research methods (Creswell and Plano-Clark 2006; Wilson and Corlett 1995).

16.3.5 Strategies for Design

Earlier in the chapter the need to define a market size in order to choose the manufacturing process and associated materials was described. The generic processes involved in any NPD are constrained by similar elements that match particular design choices within the PDS. While these will be acknowledged, the focus of the remaining section of this chapter will discuss the pros and cons of methods and tools specific to the design of products or services in the field of universal and inclusive design.

The aim of any commercial designer is to produce an optimum design solution within the shortest development time and effort. There are many good reasons to get the product to market as soon as possible: from the moment research data are collected, they are "decaying" in validity. Society and culture can change in minutes. A good example is the field of fashion design within which trends change quarterly, if not weekly. The shorter the time period from inception to the realization of an NPD reduces overall costs and the time to start generating a return on funds invested. The market for enabling products and services is more driven by return on investment, due to the small market size and the often smaller investors who are involved at a personal level.

16.3.6 Participatory Design

A participatory design strategy provides an opportunity to minimize the number of development cycles and get the product to market.

The iterative cycle of design development that includes end users, proposed by Papanek so many years ago, is still valid in current design practice. The data collected from the mixed methods approach should provide a detailed profile of the UTE. The design methods to be used within an iterative cycle of development include:

- Co-designing (blacksmith approach)
- Design heuristics (rules of thumb)

16.3.7 Co-designing

Co-design is a form of participatory design activity, originating from a systems engineering approach; in this case, it refers to a one-to-one design activity with the designer. It is also known as co-discovery (Kemp and van Geldren 1996). The term "blacksmith approach" comes from a traditional way that people in the UK would have had things made. Blacksmiths may be considered the product designers of the pre-industrial age. A villager would ask the blacksmith to make a new gate, for example; possibly standing by while it was fabricated. Designing for and with an individual who represents a larger population of end users has been found to be useful when considering niche markets. This approach has a number of advantages:

- The direct link between designer and end user ensures that the design decision-making process results in the minimum of iterative cycles of development.
- The less well defined, qualitative areas of aspirations for the product and desirability are also addressed.
- There is an opportunity for end users to be made aware of design solutions they may not have previously considered.
- Iterative design cycles, in the form of co-design, enable the optimum compromise to be achieved quickly.
- The end user has a sense of ownership with the final design solution.

A product design, or service, may be evaluated with a larger sample group once the design solution has been developed with the "product champion," with the confidence that investment in this activity is cost effective. The methods used to elicit information from the champion user are repeated with a larger sample group at an individual level. The efficacy of information gathering has been found to diminish when obtaining feedback within a group situation, such as when using a focus group strategy.

16.3.8 Design Heuristics

Design heuristics (rules of thumb) effectively facilitate the interpretation of the functional needs and aspirations of the target user, while satisfying the standards set by the stakeholders. The design heuristics include:

- Persona footprint
- Adaptability and flexibility (standardization and modularity)
- Use of original equipment manufacturer (OEM) parts
- Customized interfaces and rapid manufacturing (RM)
- Minimize financial and liability risk

16.3.8.1 Persona Footprint

The persona footprint is the visual balance between the enabling technologies associated with an individual and the presence of that person. This design heuristic enables a practitioner to quickly assess the area of visible technology compared with that of the person. The objective is to minimize the perceived technology and emphasize the personality of the individual. Strategies for this include:

- Minimize the volume of the technology (compact electronics, body contoured supports and seating, fold-away items)
- Break the technology into smaller elements (battery pack on a belt, not part of the communication device)
- Use of color to make technologies recessive (dark colors, matt textures)
- Customizing the technology to the individual's personality and value system, branding (symbols and colors of a favorite football team)

An example of a persona footprint is shown in Figure 16.6, where students have endeavored to reduce the technology footprint around a powered wheelchair user who also uses a communication aid.

16.3.8.2 Adaptability and Flexibility (Standardization and Modularity)

Adaptability and flexibility (standardization and modularity) embody the application of the seven principles of universal design. Good examples include "plug and play" computer technology; and applications, "apps," for i-Pod touch and other hand-held computer products.

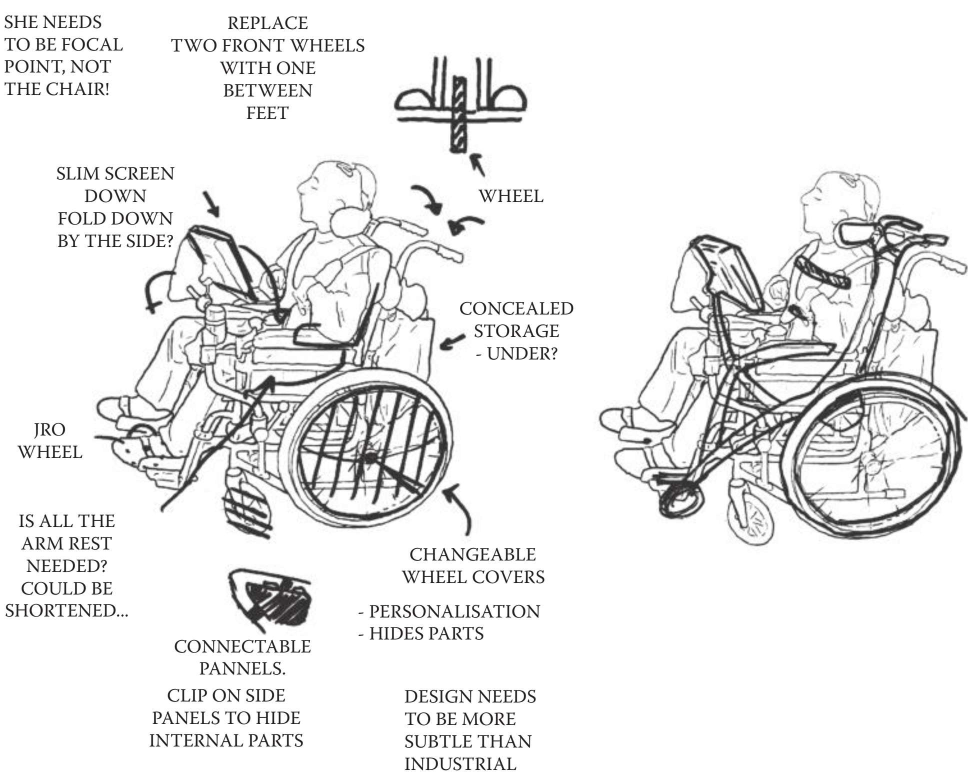


FIGURE 16.6 The reduction in technology footprint on the persona of the user. (From Allen et al., *Postgraduate and Undergraduate Exercise, Universal and Inclusive Design Module*. Loughborough Design School, Loughborough, 2000b.)

Standardization and modularity are engineering conventions that enable adaptability and flexibility of functions. Using a standardized physical or electronic interface reduces costs and offers the maximum options within a product (Burkitt et al. 1995; Torrens et al. 1996). The same principles may be applied to a product service. There are many good references that describe both modularity and standardization (Ulrich and Eppinger 2000).

16.3.8.3 Use of Original Equipment Manufacturer Parts

Use of OEM parts has a number of advantages:

- Complex functions of a new product design may be bought rather than manufactured (e.g., USB connectors, electronic subassemblies, gear boxes, electric motors, switches).
- Safety critical items can be purchased that are to a known manufacturing and performance standard (e.g., switches, sensors, hydraulic cylinders, brakes, bearings).
- Prototypes may be constructed cost effectively that represent the final production version.

An important point to consider when applying this particular heuristic or strategy is that it is employed from the start of a design process. Once a PDS has been produced, the identification of suitable OEM parts should be the first task. Some accommodation of the specification for the OEM part may be needed within the overall design.

16.3.8.4 Customized Interfaces and Rapid Manufacturing (RM)

Customized interfaces and RM are a recent addition to the options available to a product designer. Previously used for rapid prototyping, the industry has evolved to such a level that RM in polymers and sintered metals are already used to tailor high-end products to a customer's preference. They can also be used to tailor garments to individuals. Examples include, switch or control interfaces, orthotic supports and grips. High-end refers to the high cost and high value of the product. RM components can cost effectively provide customized physical interfaces for more severely physically impaired individuals that link with standardized components within the product assembly. Examples include seating through to a geared drive train or a wheelchair chassis.

16.3.8.5 Minimize Financial and Liability Risk

Minimizing financial risk may be considered an overarching generic objective of any business. Most of the elements of an NPD described in this chapter lead to reduced cycles of development by providing evidence of the potential need and desirability of the realized product. Threats from litigation can be minimized through rigorous, iterative cycles of evaluation and that products are tested through independent test houses or laboratories to ensure the design audit trail. Following the guidelines of BS EN ISO 7000-1: 2008 (British Standards Institute 2008) for design and engineering management, in whatever simplified form, is good working practice. There is also a sub-section relating to design for inclusivity BS EN ISO 7000-6: 2005 (British Standards Institute 2005). Advantages of this practice include:

- Evidence-based, transparent decision making within the NPD documented
- Enables other or new design team members to have empathy with past design decisions
- Demonstrates all due care has been taken in the design, if litigious action is taken at a later date
- Provides proof of originality in the event of a dispute over intellectual property rights (IPR)
- Enables potential investors to assess the products in which they may invest

16.3.9 Increasing Your Target Market: Matching Product Design Specification

Papanek (1974) indicated how to increase your market; design for one very well and look for others who share the same needs. Increasing your target market may be achieved by finding other UTEs

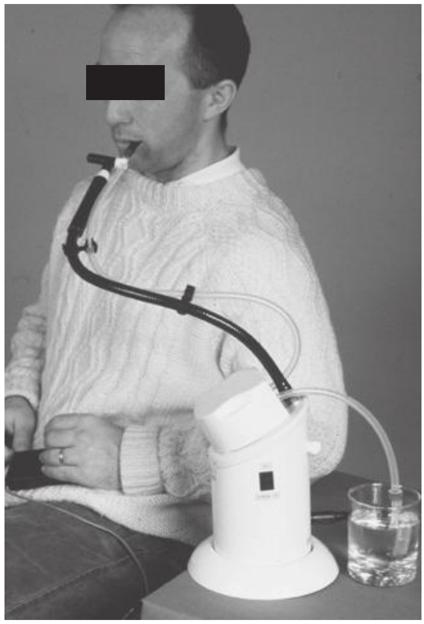


FIGURE 16.7 An automated drinking device, the Autosip, being tested by the author in 1992 at the Brunel Institute for Bioengineering.

that require the same or very similar PDS. A powered drinking device, the Autosip (Figure 16.7), designed for the Motor Neurone Disease Association by the author in 1992 (Burkitt 1995) provides a good example of this principle.

Designed and developed for members of the association who had limited ability to swallow, it delivered 2 mL of fluid to the mouth in a controlled speed and feed. This avoided the likelihood of the end user choking on the fluid. At the time, variations on the design were aligned with other markets, including racing drivers, military drivers, and extreme outdoor activities, such as rock climbers. All may need fluid replacement, hands-free.

The design heuristics described above have been used within product design developments over the last 20 years. The following is a reflection on the strategies and methods discussed.

16.4 CONCLUSION

To conclude this description of strategies and methods, a checklist of strategies and methods that may be used within an NPD has been defined to provide the reader with a structure for reflection. The checklist includes:

- Seven principles of universal design
- Predictive modeling
- Empathic modeling (replicating the physical elements of a medical condition)
- Product champion designing (blacksmith approach)
- Persona footprint
- Standardization and modularity (application of universal design principles)
- Use of OEM parts
- Customized interfaces and RM
- Minimize financial and liability risk
- Matching PDS

The strategies and methods described here are not all encompassing; however, they are the ones found to be useful by the author as a practicing designer. The bibliography contains many of the references found useful by the author. It is hoped that the methods and resources mentioned here will be of equal use to the reader.

REFERENCES

Allen, S.M.D, Day, J.L., Rishikesh Hanumant, R., Gallimore, L., Johnson, D., and Milner, D. 2010a. A Mind map of the relationship between the user, task, and environment within the context of daily living activities of a wheelchair user. *Post-graduate and Undergraduate Exercise, Universal and Inclusive Design Module*. Loughborough: Loughborough Design School.

Allen, S.M.D, Day, J.L., Rishikesh Hanumant, R., Gallimore, L., Johnson, D., and Milner, D. 2010b. The reduction in technology footprint on the persona of the user. *Post-graduate and Undergraduate Exercise, Universal and Inclusive Design Module*. Loughborough: Loughborough Design School.

British Standards Institute. 2005. *BS 7000-6:2008 Design Management Systems. Managing Inclusive Design Guide*. London.

———. 2008. *BS 7000-1:2008 Design Management Systems. Guide to Managing Innovation*. London.

Burkitt, J.A., Torrens, G.E., Kay, G.H., Sandbach D., and Sutherland, I.A. 1995. The development of the Autosip: A hygienic, self-operated, drinking device for people with minimal sucking ability and/or minimal arm strength. *Journal of Rehabilitation Sciences [Tijdschrift Voor Revalidatie Wetenschappen]* 8 (4): 115.

Christophersen, J., and Norske stats husbank. 2002. *Universal Design: 17 Ways of Thinking and Teaching*. Oslo: Husbanken.

Cohen, L., Mannion, L., and Morrison, K. 2007. *Research Methods in Education*. 6th ed. London, New York: Routledge.

Creswell, J.W. 2009. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 3rd ed. Thousand Oaks, CA: Sage.

Creswell, J.W., and Plano-Clark, V.L. 2006. *Designing and Conducting Mixed Methods Research*. Thousand Oaks, CA; London: Sage.

Engineering Design Centre. 2010. *Inclusive Tool Kit, 2010.* http://www.inclusivedesigntoolkit.com/ (accessed May 19, 2010).

Ergonomics and Safety and Research Institute. 2010. *Third Age Suit*. http://www.lboro.ac.uk/research/esri/design-safety/projects/sim_suit/thirdage.htm (accessed May 19, 2010).

Her Majesty's Government. 2010a. *National Statics Office, Population Trends*. http://www.Statistics.Gov.uk/populationtrends/downloads/Pop-Trends-spring10.pdf (accessed May 19, 2010).

———. 2010b. *National Office of Statistics, Population Estimates for UK, England and Wales, Scotland and Northern Ireland – Current Datasets.* http://www.Statistics.Gov.uk/statbase/Product.Asp?vlnk=15106 (accessed May 19, 2010).

———. 2010c. *National Statics Office, Aging.* http://www.Statistics.Gov.uk/ageingintheuk/default.Htm (accessed May 19, 2010).

———. 2010d. *National Office for Disability Issues, Disability Prevalence.* http://www.Officefordisability.Gov.uk/docs/res/factsheets/disability-Prevalence.Doc (accessed May 19, 2010).

Keates, S., and Clarkson, P.J. 2003. *Countering Design Exclusion: An Introduction to Inclusive Design*. London: Springer.

Kemp, J.A.M., and van Geldren, T. 1996. Co-discovery exploring: An informal method for iteratively designing consumer product. In *Usability Evaluation in Industry*, eds. P. W. Jordan, B. Tomas, B. A. Weerdmeester and I. L. McClelland, 139–46. London: Taylor & Francis.

Langford, J.D., and McDonagh, D. 2003. *Focus Groups: Supporting Effective Product Development*. London: Taylor & Francis.

Loughborough University. 2010. SAMMIE CAD. http://www.lboro.ac.uk/departments/cd/research/groups/erg/sammie/home.htm (accessed May 15, 2010).

Morgan, D.L. 1997. *Focus Groups as Qualitative Research*. Qualitative Research Methods Series, 2nd ed, vol. 16. London: Sage.

Open Ergonomics Ltd. 2000. *PeopleSize, 2000.* http://www.openerg.com/ (accessed August 29, 2009).

Papanek, V. 1974. *Design for the Real World: Human Ecology and Social Change*. St Albans: Paladin.

Porter, J.M., Case, K., Marshall, R., Gyi, D., and Oliver-Sims, R. 2004. 'Beyond Jack and Jill': Designing for individuals using HADRIAN. *International Journal of Industrial Ergonomics* 33 (3): 249–64.

Poulson, D., Ashby, M., Richardson, S., and TIDE User Consortium. 1996. *Userfit: A Practical Handbook on User-Centred Design for Assistive Technology*. Brussels: ECSC-EC-EAEC.

Sandhu, J., and Wood, T. 1990. *Demography and Market Sector Analysis of People with Special Needs in Thirteen European Countries: A Report on Telecommunication Usability Issues.* Newcastle upon Tyne: Special Needs Research Unit, Newcastle upon Tyne Polytechnic.

Torrens, G.E. 2000. The implementation of a user-centred design approach by student industrial designers when designing for elderly and disabled people. *The Design Journal* 3 (1): 15–30.

Torrens, G.E., Marshall, R., Burkitt, J., and Kay, G. 1996. Using modularity to produce more competitive assistive technology products. Paper presented at IMC-13 Annual Conference of the Irish Manufacturing Committee, University of Limerick.

Ulrich, K.T., and Eppinger, S.D. 2000. *Product Design and Development*. 2nd ed. London: McGraw-Hill.

Wilson, J.R., and Corlett, E.N. 1995. *Evaluation of Human Work: A Practical Ergonomics Methodology*. 2nd ed. London: Taylor & Francis.

World Health Organisation. 2010. *International Classification of Function, Disability and Health*. 2010: http://www.who.int/classifications/icf/en/ (accessed February 17, 2011).

17 Integration of Elderly Users into Product Development Processes: Senior Research Groups as Organizational and Methodical Approach

Sebastian Glende and Wolfgang Friesdorf

CONTENTS

17.1 INTRODUCTION

Aging of societies is happening in many industrial nations and is often seen as a challenge, if not a problem. Negative effects arise particularly from social distance and neglecting the potentials of consume and productivity. Social contacts, the impartment of knowledge, and self-realization are crucial factors for a fortunate aging (Zimbardo 1995; Maslow 1970).

The combination of reasonable engagements and liberties in a senior's life can add a high value and fulfil human needs. But constraints seem to exist that foreclose this to many elderly people (see Section 17.2.3).

Initially, it is important to take a look at the basic conditions that lead to the described phenomenon. As a result of demographic changes and medical-technical progress, the percentage of elderly people is steadily growing in Germany and other industrial nations. German prognoses are predicting an increase of life expectancy until 2050 of about 6 years to an average of 84 years. More than one-third of the population will be 60 years and above. Furthermore, the old-age dependency ratio—the number of persons above 65 years of age per 100 persons of working age (15–64)—will rise from 0.44 today to 0.71 in 2050, even when underlying a best case scenario (Pötzsch and Sommer

2003). This implies that a decreasing percentage of the population has to finance the social security system for a growing number of retired people.

As a result, aging is perceived as a financial burden in public discussion. Public expenses for annuities, care, and health systems are boosted, leading to a strained relationship between the generations (Kruse 2005). The economic potential that arises from the demographic change is hardly taken into account. On the one hand, “seniors” are shaping an enormous sales market. Some examples: People older than 50 years have more than half of Germany’s spending power and assets, they buy more than 45% of all new cars, 50% of skin care products, and they book about 35% of package holidays (Klesse 2006). On the other hand, elderly people have a rich know-how based on experience. They are willing to use and share it in social, cultural, and technical areas. Unfortunately, access to new media technologies—which is fundamental for many activities—remains limited for the elderly due to usability issues (Figure 17.1).

This leads to the main question considered here: What drawbacks exist in human–machine interaction for the elderly and how can senior people take an active part in the elimination of these? This analysis obviously leads to many more questions, e.g., how social and economic barriers in employment and the sales market can be overcome.

17.2 BASIC CHARACTERISTICS OF THE MARKET SEGMENT 55+

In this chapter, barriers are identified that are responsible for the poor use of seniors’ potential, based on actual employment statistics and typical characteristics of elderly people. Furthermore, inappropriate market segmenting on the basis of rigid age limits as well as product development only from a technical point of view and its effects have to be considered.

17.2.1 Employment of the Market Segment 55+

Today, the border between the working and not working population is determined by age, not by criteria, such as qualification, motivation, or vocational success. Each discussion about raising the retirement age from 65 to 67 years or above creates vehement protest. Due to the perception of work as a burden, a discussion about voluntary work after retirement hardly exists. Nonetheless, a decision about employment for seniors based on performance and motivation is missing in Germany and other industrial nations (Kruse 2005). Compared to the international average, the unemployment rate of people aged 50 and above is considerably higher (>30%) in Germany. A distinctive willingness to retire early, little investment in qualifications, and serious age discrimination are primary reasons for this situation.

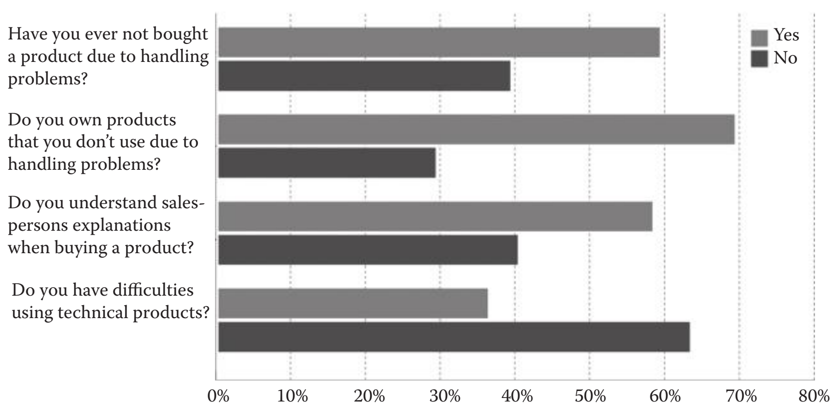


FIGURE 17.1 Results of the SENTHA survey “Use of technical devices” with 130 participating seniors.

Due to the profound technological changes, it becomes increasingly difficult for elderly persons to adapt their qualifications to the requirements of work. A relatively large portion of people aged 50 years and above abandon work before reaching the defined retirement age of 65. Changing occupation is uncommon among elderly employees for economic reasons, as qualification programs may not amortize before retirement.

Underfunding qualification measures for the elderly combined with the demographic change increases the risk of losing international competitiveness. Aging of employees leads to an aging of the knowledge of the society, which impairs the growth determinant "technological progress."

But so far, attempts to reduce this risk are insufficient. At least the goal of increasing employment of the elderly has reached the top level of macroeconomic policy. Furthermore, the increasing demand for unsolicited qualifications shows—against operational experiences—the motivation and interest of the considered target group.

17.2.2 Sales Potential of the Market Segment 55+

The market segment 55+ offers a huge turnover potential, which is not utilized today. In Germany, people older than 50 years dispose of 48% of all incomes, even though this segment only represents 35.5% of the German population (Klesse 2006). Furthermore, seniors have the time for leisure activities and shopping—more than during their working life. This creates good opportunities for successful marketing. The generally high propensity to consume does not apply to electronic devices and computer equipment owing to a lack of knowledge about the requirements of elderly user groups. As a result of the strong market growth in the area of mobile phones and computers for the last years, there has been low-level interest in user-oriented development of high-tech products. Still today, a large part of products, services, and advertising campaigns developed for the considered market segment is based on stereotypes of physically disabled and thrifty pensioners. This sets a difficult environment for product innovations.

Despite this, one indicator points to the existing interest in new media and technology: The degree of web utilization is growing strongly within the market segment 55+. But this arises mainly from better training than from product adaptation.

During the last year, utilization of the World Wide Web has increased by 3% to 34% within the so called "Best Agers" (people 55 years and above). On closer examination, strong distinctions between segments of the target group "seniors" become apparent: The younger the segment, the higher the utilization of the web. Despite the low market saturation of 12.2% within the group 70 years and above, an increase of only 2.4% occurred (Möller 2006).

Analogical to the demographic segmentation in the employment market, the sales market 55+ is structured only by age. This is insufficient, since even younger target groups are segmented by manifold criteria, although interpersonal differences can be more explicit in the elderly due to experience of life. Differences related to economic status, social class, and education intensify with higher age. Combined with the diversity in physical and mental capabilities, the inhomogeneity is incomparable to younger target groups. In order to use the sales market potential, the conjunction between personal circumstances as well as behavior (e.g., family ties, intergenerational contacts, education, use of media, etc.) and buying behavior in various fields of products and services has to be researched.

Among others, decreased average size of households (from 5.5 to 2.2 persons within the last century) leads to more mobility and flexibility and to the higher importance of leisure and consumption. Due to the changing attitudes, a new demand for consumer and technological products has emerged, which has not been satisfied so far.

In terms of marketing and communication with elderly people, serious weaknesses appear: In a survey by a German market research company (GfK) more than 50% of people of 50 years and above state that it is noticeable that advertising campaigns are created by younger persons. User integration is implemented in the conceptual design of advertising just as little as in product development. Companies still assume a high brand loyalty for seniors, even though this only applies for the segment above 75 years, which is a small part of the senior market. Everybody wants to get old but nobody wants to be—this assumption has been validated in several surveys and seems to be essential for successful campaigns (Gaspar 2000).

Besides marketing, an adequate conceptual design of products is most important to tap the full market potential. Today, less than one-third of all enterprises think about cultivating the senior market. Estimates of GfK claim that the "Generation 50+" in Germany has an idle spending power of more than €100 billion annually. For lack of appropriate products this amount remains unspent, which causes considerable damage to the German economy.

If seniors' needs are considered in product design today, most of the developed products claim to be "barrier-free."* This type of design is oriented to deficits of the elderly, not to resources and potentials. For this reason, it contributes to stigmatization and equalization with disabled people. But with this image, healthy and active seniors cannot be addressed effectively.

To benefit from the described market potential and to attain economic revival, user integration with elderly people has to be supported and promoted by industry, media, and public organizations (Kruse 2005).

17.2.3 Barriers to Employment and Sales

Commonly, the ability to work is composed of the personality (health and competence), working process (content of work, stress), and culture (moral concept, social conditions, management, team) (Karazman, Kloimüller, and Arato 2003).

The basic work interest is particularly influenced by culture and can represent a serious barrier. For example, ageism, early retirement, a lack of qualification measures, and little confidence in utilizing technical products are the most obvious problems.

Moreover, ability and interest to work are affected by a factor that is not part of the described theoretical framework—the working appliance or implement. Hetze (2005, 8) suggests the importance of this factor: "The percentage of low qualified elderly unemployed persons is particularly high in nations with an above-average growth of productivity and technical progress." Owing to the gap between job requirements, e.g., the utilization of information technology, and competences of seniors, access to the job market is restricted. Two strategies are appropriate to solve this: On the one hand, use training, which can also be regarded as adaptation of human to machine and an indirect solving strategy, could be promoted. On the other hand, the user-friendly design of products could be implemented in product development by user integration (Figure 17.2).

Some commonly accepted causalities concerning the skills of elderly persons have to be ascribed to the missing user integration. Absence of mental flexibility, a lack of innovative ability, and learning aptitude do not have to be considered as results of aging, but as long-term effects of product development only from a technological point of view (Pack 2000; Glende 2010).

One reason for the scant regard for user needs is the complexity of today's product development processes with small capacities for integration of additional information and sub-processes. Methods for analyzing user behavior and requirements are often inapplicable due to costs, time constraints, and extensive interference with other sub-processes of the design process (Blessing 2007).

An assumption, often expressed by technically oriented product developers, is that this problem will be solved over time, because future generations of senior citizens will be more familiar with computers and other technical devices due to a longer period of experience. But the rapid evolution of technologies without adaptation to user capabilities may lead to more complex products than people can manage with their experiences.

Particularly with regard to motivation to voluntary, social, or cultural activities after reaching retirement age, user friendly design and fun to use products are essential. In this context, another barrier can be identified—the focusing on physical human–machine interaction without consideration

* cp. Pichert, H. (1999, 35).

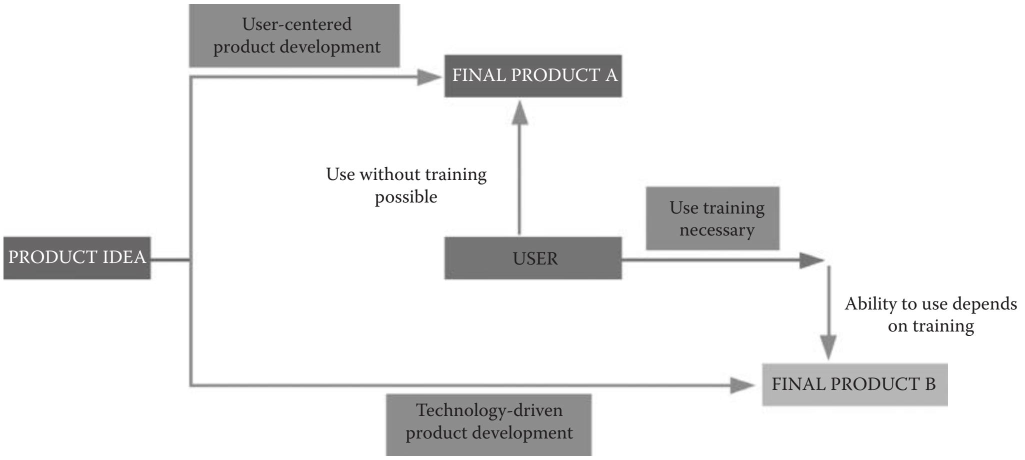


FIGURE 17.2 User-centred vs. technology-driven product development (own research).

of the mental and psychological aspects (Figure 17.3). Mental interaction, which is based on understanding the use-logic, is essential to prevent users' frustration and non-acceptance of new technologies. To focus on elderly user needs, their know-how and opinion have to be used during product development. A complete empathic approach by younger engineers is unrealistic, since personal experience with technical products, as well as mental attitudes, are too different.

The biggest problems occur in the psychological areas of interaction. Products well adapted to seniors' physical needs are often characterized by unattractive design. Mobile phones the size of pocket books and ergonomic clothes contribute to stigmatizing elderly people.

17.3 SENIOR RESEARCH GROUP AS APPROACH TO SOLUTION

Described problems can be solved by involving target groups, especially seniors, in product development processes. To ensure success, orientation on existing industrial development processes is necessary. These are mostly standardized and sub-divided into various phases, from generation of ideas to conception of marketing strategies. Phases are often finished by quality gates, which are milestones where compliance to requirements is audited (Pahl and Beitz 1993; Glende 2010). To set the preconditions for more user influence during product design, organization of user know-how and user integration methods are fundamental. A theoretical model of senior research groups (SRGs) is illustrated in the following Sections 17.3.1–17.3.3. Aims, organizational structure, and methods as well as exemplary

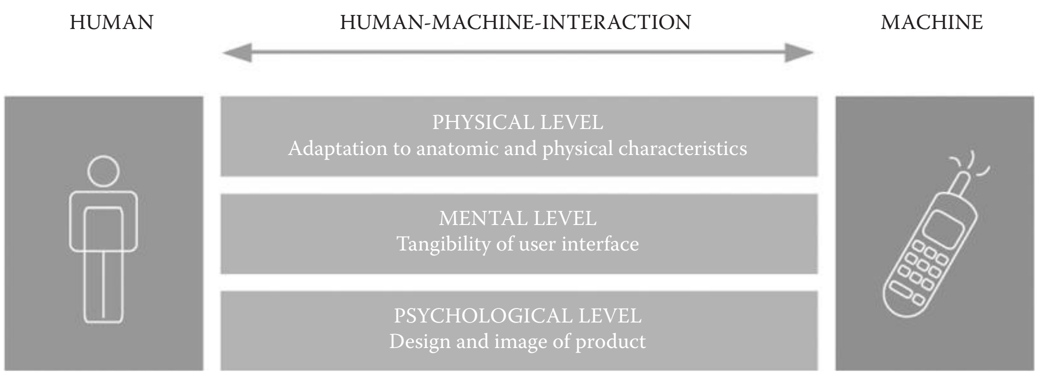


FIGURE 17.3 Levels of human–machine interaction (own research).

results of user integration are described according to industrial product development processes. Additionally, first practical experiences with the implementation of this concept are portrayed.

17.3.1 Aims and Benefits of Senior Research Groups

The superior aim of SRGs is influencing and advancing the design of technical products and services to enhance quality of life and enable the utilization of elderly people's employment potential. User integration can improve the competitiveness of seniors by facilitating the use of technical work equipment, thereby increasing efficiency of work. Various sub-goals—known as dialogue principles and standardized with ISO 9241 "Ergonomics on Human System Interaction" Part 110—are part of this idea (Luczak 1993). In particular, self-descriptiveness and error tolerance depend on user experience and behavior and require user integration during design.

SRGs should create and use a pool of knowledge, methods, and testbeds and support industrial product developers as consultants and test persons. They strive for emancipation of the elderly generation by revealing customer needs and requirements and avoiding just adaptation to existing user interfaces (Glende 2010).

Not least, SRGs can underline the special capabilities of the elderly, like quality awareness, loyalty, and working morale as well as counteract the image of decreasing innovative ability and creativity.

17.3.2 Organizational Structure of Senior Research Groups

An SRG has to be able to represent the needs of as many seniors as possible. For this reason, a heterogeneous team, combining age structure, education, work interest, and social background has to be organized. The combination of technical experienced and inexperienced users can be recommended.

To facilitate the validation of research and test results, two user groups have to exist in parallel. On the one hand, a core group to attend to product development tasks. An adequate size that allows efficient workings as well as enough different points of view is between 15 and 25 members. On the other hand, an alternative structure for surveys to get information about needs, interests, and acceptance of products and functions has to be provided. For that purpose, about 100 seniors should be selected as a senior pool, representing people aged 55 years and over. This structure can be used to validate the work results of the core group and field tests. For both core group and senior pool a continuous recruitment of young seniors is essential. Within an SRG, various sub-groups can be established to assume organizational and representative tasks like project management, documentation, and finances (Figure 17.4).

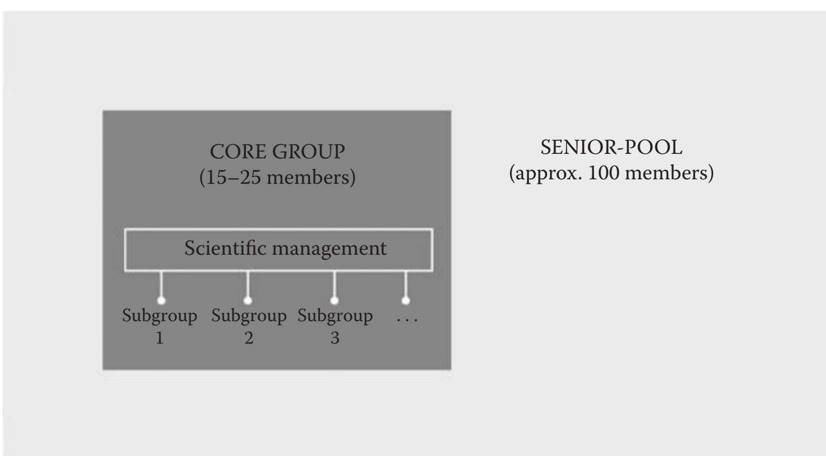


FIGURE 17.4 Organizational structure of senior research groups.

The group has to be managed by scientists that are skilled in product development as well as user integration and test methods, which make users' creativity and experience accessible.

17.3.3 Recommended Process for User Integration During Product Development

The aim of user integration during product development is the detection and elimination of ergonomic weaknesses. With an iterative procedure and the continuous involvement of SRGs as potential users, a systematic improvement of products is approached. Furthermore, typical user requirements and design mistakes should be identified and included in checklists. Thus, a standardization of ergonomic product development can be supported. This standardization is a key factor for dissemination of ergonomic knowledge—only easy to understand, transparent, feasible, and cost-effective user integration processes will be considered for integration in existing complex product development structures.

The ergonomic optimization is processed synchronously to typical phases of product development. It is structured in six steps with different methods for analyzing and evaluation (Figure 17.5).

Phase 1: Definition of general conditions and objectives

- State-of-the-art description regarding technological and scientific results and developments related to the considered product, its possible applications, assets, and drawbacks.
- Demarcation of target groups concerning age, health, education, social background, etc.
- Demarcation of scope of application with a temporal, spatial, and task-related focus.
- Basic design of testbeds.

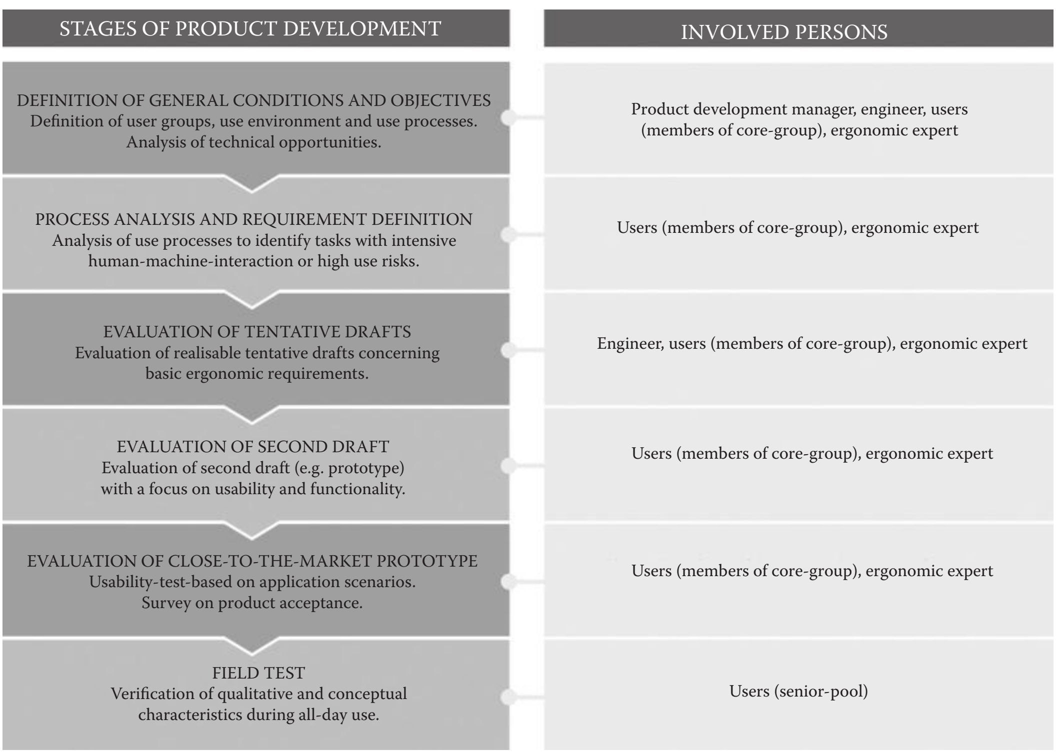


FIGURE 17.5 Product development process from user integration point of view. (From Backhaus, C., Entwicklung einer Methodik zur Analyse und Bewertung der Gebrauchstauglichkeit von Medizintechnik, dissertation at the Technical University Berlin, 2004.)

Phase 2: Process analysis and requirement definition

- Analysis and visualization of possible use processes.
- Identification of user group and characteristics, use-tasks, and use-environment requirements based on analyzed use processes, afterwards compilation of requirement list.
- Identification of usability relevant tasks with a high interaction rate between human and machine.

Phase 3: Evaluation of tentative drafts

- Development and discussion of various tentative drafts by means of drawings or mockups with seniors.
- Evaluation of feasibility and pre-selection of design elements with a high impact on usability.
- Inquiry within the senior pool, aiming at validation of pre-selected tentative drafts.
- Further development of requirement list.

Phase 4: Evaluation of second draft

- Evaluation of second draft (prototype or software simulation), focused on user interface, with a cognitive walkthrough (Nielsen 1994), conducted by the core group.
- Weighting of identified usability weaknesses in reference to its relevance.
- Revision of requirement list.

Phase 5: Evaluation of close-to-the-market prototype

- Usability test on the basis of selected application scenarios with six or more members of the senior pool who have not been involved in the development process before.
- Survey on product acceptance within the senior pool, e.g., with the systems usability scale (Brooke 1996).
- Interviews aimed at identifying usability strengths and weaknesses.

Phase 6: Field test

- Product use by members of the senior pool in real use environments with a duration of one to four weeks, depending on use frequency and product complexity.
- Documentation and iterative optimization of usability weaknesses until product launch.

17.3.4 Hands-on Experience: The Senior Research Group

The Department of Human Factors Engineering and Product Ergonomics at the Berlin Technical University works with about 20 seniors on realizing the described concept. Experiences from the interdisciplinary research project SENTHA (German acronym for senior-compatible-technologies in everyday life) led to continuation of the work with elderly persons in product development. The “senior research group” was first founded as a test group, expanding their field of activity to consultancy with product developers, and is now involved in various stages of the entire product development process (Figure 17.6) (Glende 2010).

Due to the organizational connection between university and SRG, synergies from intergenerational projects with students and seniors have been generated. Besides product development, seniors contribute to a better understanding of elderly people’s requirements and needs. Projects with students aimed, for example, on the development of sports equipment for people of 55 years and above, are characterized by active interaction between students and the SRG members.

In addition to concrete results—observable in products of consulted companies— the SRG’s work leads to further findings about the ergonomic requirements of the elderly as well as processes of user integration.

Demands concerning SRGs can be enhanced with hands-on experience. This contributes to the optimization of the delineated theoretical concept (cp. Chapter 3.3). But working with the SRG

FIGURE 17.6 Senior research group members at work. (From Glende, S., *Senior User Integration – Konzepte, Werkzeuge und Fallbeispiele*, SVH, Saarbrücken, 2010.)

shows that the integration of user-centered product development processes by manufacturers is a major problem. The involvement consists mostly of participation after the completion of the basal design process, thereby limiting the users influence to a minimum. In this regard, a need for more educational advertising of manufacturers remains.

17.4 DISCUSSION AND FUTURE PROSPECTS

The presented concept shows how user integration with seniors can be effective against profound risks and problems in social security systems in the long run. Optimization of technical products usability is a precondition for fundamental economic and social changes concerning demographic changes (Figure 17.7).

User integration conducted with elderly persons generates new work areas and jobs for the “Generation 55+.” Economic pressure coming from low-wage countries demands a focus on research and development in industrial countries, which implicates a great potential for seniors involvement. For seniors, it is more difficult to compensate for the ergonomic defects of technical devices than for younger people. For this reason, they are more suitable test-persons to identify those defects.

A big employment potential arises from the results of user integration: Easy-to-use products, media and communication devices help seniors to realize their own ideas and provide know-how, because efficiency-increasing products and tools become better accessible. Allocation of resources can be facilitated with the use of internet technologies, e.g., when elderly people offer their manpower online.

In addition, the high senior share of the population constitutes expectations of an increasing sales volume in this market. If—due to user integration—products and services are developed that fulfil previously unfulfilled needs, the absolute revenues of an economy rise. Ergonomically designed products are usable not only for seniors but also for younger people. Consequential competitive advantages will occur in various market segments. Secondary economic results of the improved employment and sales situation are higher public revenues, which may support the orientation to a knowledge-based society.

If senior integration in value creation leads to economic success, the elderly are perceived as more active, creative, and innovative by society. Intergenerational collaboration is an important factor for social integration and can prevent losing know-how (Smith et al. 1996). Not least, networking between generations is a way to work against skill shortages. Such knowledge-oriented activities of seniors do not replace jobs for younger people. Intergenerational knowledge transfer, ergonomic

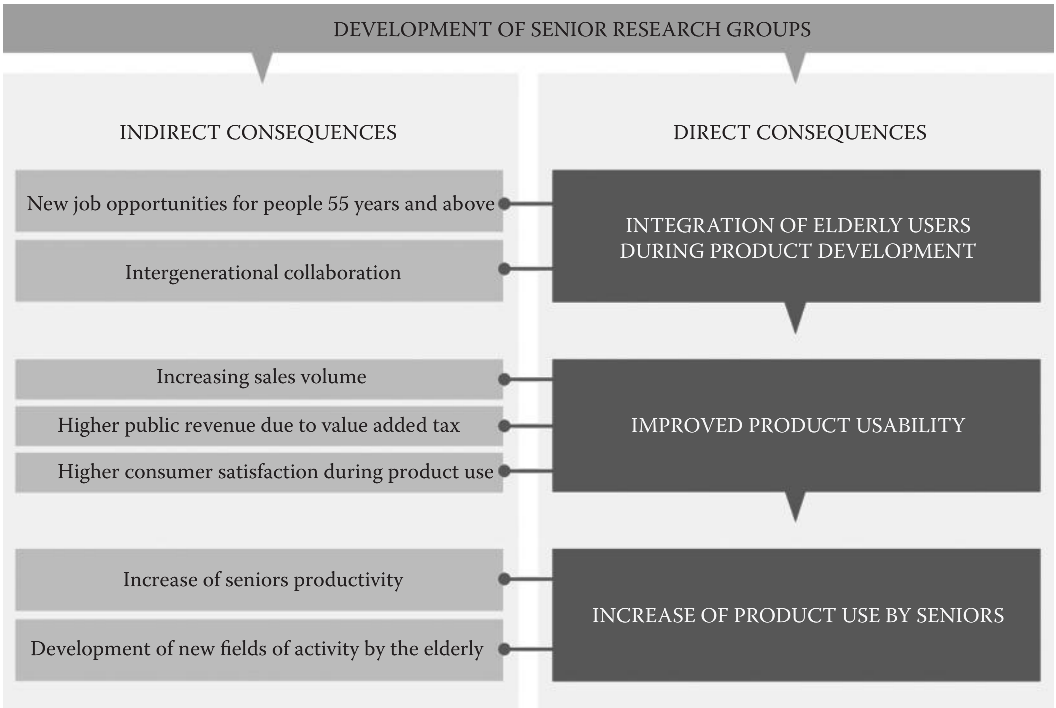


FIGURE 17.7 Direct and indirect impacts of senior research groups (own research).

optimization, product testing, and social activities are the poorly developed work areas of today and have a high potential for growth.

The activities of the SRG already proved feasibility and potential for success of described concept in several product development projects (e.g. mobile phones, remote controls). To assure the success of SRGs, standards for user integration have to be developed and improved continuously with results from hands-on experience. Best practice examples have to be diffused to encourage an international collaboration in the field of senior involvement. Besides establishing general conditions politically, an early intergenerational contact, e.g., during studies and professional education, is crucial for a better social acceptance of seniors' activities (Kruse 2005). To promote ergonomics in industrial product development, user integration processes have to be modularized and described transparently and in detail. Only this will allow product developing companies to organize and conduct such processes on their own and with small risks.

REFERENCES

Backhaus, C. 2004. Entwicklung einer Methodik zur Analyse und Bewertung der Gebrauchstauglichkeit von Medizintechnik. Dissertation at the Technical University Berlin.

Blessing, L. 2007. Methodology of Engineering Design – the Need for User Integration. Presentation at Berlin EQUID-Workshop: International Ergonomics Association.

Brooke, J. 1996. SUS – quick and dirty usability scale. In *Usability Evaluation in Industry*, eds. P. W. Jordan, B. Thomas, B.A. Weerdmeester, and L.L. McClelland, 189–94. London: Taylor & Francis.

Gaspar, C. 2000. Trends am Seniorenmarkt. In *Mit Senioren Zukunft gestalten – Dokumentation des Deutschen Seniorentages 2000*, ed. K. Siebertz, 162–66. Bonn: BAGSO.

Glende, S. 2010. *Senior User Integration – Konzepte, Werkzeuge und Fallbeispiele*. Saarbrücken: SVH.

Hetze, P. 2005. *Wissen schafft Wachstum – Auswege aus der Beschäftigungskrise?* Hamburg: Körber-Stiftung.

Karazman, R., Kloimüller, I., and Arato, P. 2003. Productive ageing – Balancing generations and managing human sustainability at work. In *Ageing and Work in Europe*, eds. H. Buck and B. Dworschak 89–98. Stuttgart: Bundesministerium für Bildung und Forschung.

Klesse, H.J. 2006. Frischer Wind – Generation 50+. *Wirtschaftwoche* 28:44–56.

Kruse, A. 2005. *Fünfter Bericht zur Lage der älteren Generation in der Bundesrepublik Deutschland*. Berlin: Bundesministerium für Familie, Senioren, Frauen und Jugend.

Luczak, H. 1993. *Arbeitswissenschaft*. Berlin, Heidelberg: Springer.

Maslow, A.H. 1970. *Motivation and Personality*. New York: Harper & Row.

Möller, E. 2006. *(N)onliner Altas 2006*. München, Bielefeld: TNS-Infratest.

Nielsen, J. 1994. *Usability Engineering*. San Diego: Morgan Kaufmann.

Pack, J. 2000. Altersneutrale und lernförderliche Gestaltung von Arbeitssystemen in Teilefertigung und Montage. In *Altern und Arbeit – Herausforderung für Wirtschaft und Gesellschaft*, ed. C. von Rothkirch, 414–21. Berlin: Ed. Sigma.

Pahl, G., and Beitz, W. 1993. *Konstruktionslehre – Methoden und Anwendung*. Berlin, Heidelberg: Springer.

Pichert, H. 1999. Neue Person-Umwelt-Gestaltung für alte (alle) Menschen – Herausforderung für Industrie und (öko-)gerontologische Forschung. In *Alte Menschen in ihrer Umwelt*, eds. H.-W. Wahl, H. Mollenkopf, F. Oswald, and F. Opladen, 184–98. Wiesbaden: Westdeutscher Verlag.

Pötzsch, O., and Sommer, B. 2003. *Bevölkerung Deutschlands bis 2050 – Ergebnisse der 10. koordinierten Bevölkerungsvorausberechnung*. Wiesbaden: Statistisches Bundesamt.

Smith, J., Fleeson, W., Geiselmann, B., Settersten, R., and Kunzmann, U. 1996. Wohlbefinden im hohen Alter–Vorhersagen aufgrund objektiver Lebensbedingungen und subjektiver Bewertung. In *Die Berliner Altersstudie*, eds. K.-U. Mayer and P.-B. Baltes, 497–524. Berlin: Akademie Verlag.

Zimbardo, P.G. 1995. *Psychologie*. Berlin: Springer.

18 IEA EQUID Template for Cooperation between Product Designers and Ergonomists

Michel Nael[*]

CONTENTS

18.1 INTRODUCTION

The EQUID (Ergonomics QUality In Design) Committee is a standing committee of the International Ergonomics Association[†] (IEA). Within this committee, a working group, the EQUID Template editing group, has developed a template document as a helping tool to design products or services that are usable by the widest number of intended customers.

18.2 NEED FOR A COMMON LANGUAGE BETWEEN DESIGNERS AND ERGONOMISTS

Difficulties of reciprocal understanding among partners are often observed in design project teams. This well-known fact is detrimental to the efficiency of projects and to the satisfaction of all partners. Our purpose here is not to develop all the reasons why misunderstandings occur, our purpose is to focus on two kinds of difficulties between designers and ergonomists who have to cooperate in designing products and services.

First, a key difficulty is in the understanding of end-users of products. Both partners refer to these users and it seems a good start for cooperation. But, in fact, each partner has his/her own idea of what the end-users actually are. As Donald Norman (1988) stated in his book, *The Design of Everyday Things*, designers and users have different "system images" of the same product. Ergonomists try hard to express the end-users' system image and to hand it over to designers, but the cultural gap between those partners can never be fully bridged. This can be observed at every language level: at lexical and syntactic levels where partners often love to express themselves in their own jargon and, as a consequence at the semantic level, resulting in numerous confusions or even total misunderstanding.

[*] EQUID template editing group: Olle Bobjer (Ergonomidesign, Sweden), Hugh McLoone (Microsoft, USA), Jiyoung Kwahk (Samsung, South Korea), Wolfgang Friesdorf and Sebastian Glende (Technische Universität Berlin, Germany), Michel Naël (Ergonomics & Design, France).

[†] Cf. www.iea.cc for further information on the IEA and the EQUID Committee now chaired by Ralph Bruder (Institute of Ergonomics, Darmstadt, Germany).

Let us now consider the design process itself. Human factors and ergonomics (HF/E) professionals are good at analyzing actual end-users and real system usage situations. Numerous HF/E methodologies, techniques, and models have been developed for this purpose (Karwowski 2001), including those described by Stanton et al. (2005). Of course, producing a valid diagnosis of end-users' problems is a basic requirement for good design. But a correct diagnosis will not automatically generate a satisfying solution. There is a second gap here, not between people, like the previous one, but between analysis and solution. As Lawson (2006, 125) puts it, "design is essentially prescriptive whereas science (ergonomists ground their methods in several scientific fields) is predominantly descriptive." Ergonomists can deliver very useful information for product design through their analyses, but their ability to directly help in creating solutions is as limited as for anyone untrained in creative design. Maybe they could be more investigative in methods and ways to better convey their messages to designers, but some divide between the analyst (the ergonomist) and the designer will always exist. One result of this situation is that designers often feel ergonomists' analysis of a particular solution (e.g., an intermediate mock-up) as a negative criticism of their own work. As a consequence, this may also impair the relationships between designers and ergonomists.

We will not elaborate too long on these communication issues although they are of pivotal importance in the progress of a design process. On the one hand, the designer tackles complex situations where "there are no definitive conditions or limits to design problems" (Buchanan 1992, 14). On the other hand, the ergonomist strives to contribute to design through a set of communication tools that must go far beyond the traditional written reports, because opportunistic and interpersonal communications can play a most important role (cf. e.g., Berends 2003, 23–24, 189–90). Of course, no template will ever solve all these issues. But the intention is to clarify, from the very beginning of a design process, what kind of output designers can expect from ergonomists and what kind of contribution they can make at crucial steps of an iterative design. The template provides all partners in the design process, designers and ergonomists as well as management (as the governing body of an organization who makes decisions in design and ergonomics matters also) with clearly stated requirements such as

- A list of crucial information that ergonomists have to deliver for the definition of users' needs.
- A basic indication of what must be done at what time in a design project regarding ergonomics.
- Management's responsibility.

Once again, these requirements will not solve all the communication issues, but the template will pave the way for better communications through clear definitions of roles and content of deliverables that ergonomists will provide in a design project. Of course, the template is written in plain English and it should be easy to understand by all partners (cf. the provisional list of key requirements in Annex 2).

18.3 IEA EQUID INITIATIVE

The EQUID project is an IEA initiative to help the public make more informed decisions about the ergonomic quality of products and to promote the integration of ergonomics into the design process. Through integration with stakeholders in the product design and development process, the EQUID project is meant to promote awareness, guidance, and recognition of ergonomics in design.*

More generally, "The mission of the IEA is to elaborate and advance ergonomics science and practice, and to improve the quality of life by expanding its scope of application and contribution to society." Let us note that this mission is very consistent with that of the International Council of

* For more details on this cf. www.iea.cc/browse.php?contID=equid_committee.

Societies of Industrial Design* (ICSID): "ICSID strives to create a world where design enhances our social, cultural, economic and environmental quality of life."

As these missions appear to converge, one may expect an easy cooperation between the two kinds of professionals. But this is not always the case and reasons for that have been given in Point 1. The objective of the EQUID Committee is therefore to develop and manage activities related to the use of ergonomics knowledge and methods in the design process. This objective is accomplished through the definition of requirements for the design process of ergonomic products or services and work systems, and this could lead to the future establishment of a certification for ergonomics quality in design processes. Currently, the focus of the EQUID program is on product and services design. Issues related to the design of work systems will be tackled in a later phase.

Today's public output of this program is the EQUID template that defines a set of requirements (cf. Annex 2) for quality management of ergonomics in the design process of products and services. Regular exchanges and discussions take place between the EQUID Committee chairman and other standardizing bodies, namely, ISO and particularly ISO TC 159, to promote the principles developed in the EQUID project.

18.4 MAKING OF THE IEA EQUID PROGRAM

Effort to establish the EQUID program originated in 2000. The IEA EQUID initiative was launched by Waldemar Karwowski, president of IEA (2000–2003), and had continued under the efforts of Pierre Falzon (IEA president, 2003–2006) and David Caple (IEA president 2006–2009). The original EQUID Task Force composed of Waldemar Karwowski, Ian Noy, Pierre Falzon, Klaus Zink, and Ken Laughery. Later on, the work of the EQUID Committee was directed by Pascale Carayon, Lina Bonapace, and Pierre-Henri Dejean, who played important roles in the EQUID development. In addition, many other participants from several IEA-member societies around the world contributed to the EQUID program development. Discussions about goals and strategies took place within the EQUID Committee and also at IEA Council level (representing federated member societies of IEA). Several draft documents were produced, regularly modified and updated between 2000 till the latest version in 2008 (cf. provisional version of the key requirements in Annex 2).

The following EQUID principles have recently been proposed:

- The intention is to address the general public and designers in particular.
- Existing guidelines may be useful but, based on experience over many years, the human factors profession feels confident it can define a limited number of requirements, i.e., much stronger and precise statements than general guidelines, that have been proven mandatory for good design from end-users' standpoint. These requirements are stated in such a way that their observance can be checked by a third party (e.g., a certifying body).
- The idea of an "ergonomic product" certification has been unanimously rejected by the EQUID Committee and by the IEA Council. Such an idea would have been alluring in a marketing perspective, but it quickly appeared as unpractical. In principle, an "ergonomic product" means it is adapted to a particular set of users, pursuing specific goals, doing a particular set of actions, in particular surroundings. Therefore, ergonomic quality cannot be attached to a product in isolation of all these conditions.
- A focus on the "ergonomic design process" for products and services has been acknowledged as relevant and promising. In fact, this brings the approach close to the ISO 9001 standard that deals with quality management systems for products and services. It focuses on the quality of the process, which will convert into the quality of the product in the end. Ergonomics is obviously a quality attribute in a product and it is not surprising that this ISO standard offers all the relevant opportunities to articulate the ergonomic tasks in a

* ICSID: www.icsid.org.

design project. Moreover, there is an important feature that EQUID inherited, in a way, from ISO: the stress on the crucial importance of the top management of an organization in many decisions relative to the implementation of ergonomic tasks and the consideration of the ergonomic inputs into the design process. This feature is generally underestimated in human factors literature and ergonomic standards and it needs to be stressed as an essential aspect of design processes. Finally, the fact that this standard is very widely known in industry is another ground to explicitly relate the EQUID template with ISO 9001.

One working group in the EQUID Committee, the EQUID template editing group (regular participants are mentioned in a note on the first page of this text), started writing a document following the principles recapped above. After numerous exchanges, it appeared necessary to check our progress by testing our draft with a sample of fellow experienced human factors professionals. That was the "First inquiry" (cf. Annex 1). Let us sum up here only the major comments that were collected:

- Overall positive judgments on the initiative and no major issue on content.
  It is necessary to improve the readability of the document (it is hard to understand for a non-ergonomics expert, difficult for all who are not already familiar with ISO 9001, the introduction is particularly difficult to comprehend).
- Usability and cost benefits aspects are not considered enough (in the introduction and the requirements) to convince product managers of the impact of ergonomics in design processes.

Based on the results of this first inquiry, the EQUID template editing group reshaped the document several times. Then, considering the language issue, it was decided to have the text written in "Basic English," a simplified subset of English, in order to make the document easy to read for all non-native speakers of English and for non-specialists in ergonomics. This was done with the help of a professional teacher in English.

The EQUID template editing group could then proceed to the "Second inquiry," targeting product managers and industrial designers, i.e., non-specialists in human factors (cf. Annex 1). The main results provided a diversity of judgments wider than the first one. This is reasonable, as the sample of professional respondents was more diverse. Some doubts and disagreements appeared about the relevance of the template, several respondents even said the requirements in the template were already implemented in their own organization so the template came too late. But a wide majority of positive replies to the questionnaire, from all categories of respondents, demonstrates that the template is useful and usable, at least ready to be experimented in the field.

18.5 EQUID TEMPLATE LIMITATIONS

The full EQUID template document in addition to the requirements (Annex 2) also comprises an introduction, a few definitions of terms, and three provisional annexes: references to other standards, some guidance for usability evaluation and bibliography, and examples of simple forms to document the implemented design process. In the second inquiry, the attention of the respondents was drawn to focus on the requirements that constitute the template itself. As a consequence, other parts of the document and particularly the annexes have not been closely examined; they are unfinished and must be developed. In fact, the request for illustrative annexes was repeatedly expressed in both inquiries. However, in its present form, the EQUID template can already be used by designers and ergonomists as a framework to help them define a set of basic rules to cooperate. The EQUID Committee will appreciate and consider all feedback from readers and practitioners who experiment an implementation of the templates.*

* Contant point can be found on www.iea.cc/browse.php?contID=equid_committee.

Finally, and consistently with the principles defined at the beginning of Point 3, the EQUID template is not a document for product certification. It is a reference document with the copyright of the IEA that may be quoted to claim (under claimants' responsibility) that a specific design process actually complies with the requirements stated in the IEA EQUID template.

18.6 CONCLUSIONS

The EQUID template could be improved on a number of points; nevertheless, it is already a usable tool that can be useful and improved through experimentation. One regularly pointed weakness is the lack of good examples in the appendices, but these can be easily provided by the widely experienced contributors to the EQUID project.

Finally, sticking to the letter of the law, a template would not fit into design processes that inherently demand creativity and flexibility. Efficient cooperation between designers and ergonomists requires all partners to overcome their particular mindsets and this cannot be enforced by law only. This is also a matter of personal and professional attitudes during interdisciplinary team work, for which there is regretfully little or no training in traditional curricula; however, although worthy of careful attention, this is another topic.

REFERENCES

Berends, J.J. 2003. Knowledge sharing in industrial research. Doctoral dissertation. Technische Universiteit Eindhoven.

Buchanan, R. 1992. Wicked problems in design thinking. In *The Idea of Design*, eds. V. Margolin and R. Buchanan, 3–20. Cambridge, MA: MIT Press.

ISO 9001:2008. Quality management systems – Requirements.

Karwowski, W. (ed.). 2001. *International Encyclopedia of Ergonomics and Human Factors*. London: Taylor & Francis.

Lawson, B. 2006. *How Designers Think. The Design Process Demystified*, 4th ed. Oxford; Boston: Architectural Press, Elsevier.

Norman, D.A. 1988. *The Design of Everyday Things*. New York: Doubleday.

Stanton, N., Hedge, A., Brookhuis, K., Salas, E., and Hendrick, H. (eds.). 2005. *Handbook of Human Factors and Ergonomic Methods*. Boca Raton: CRC Press.

ANNEX 1 SUMMARY OF RESULTS FROM THE TWO INQUIRIES ON THE EQUID DOCUMENT

First inquiry (EQUID template version 1.04, May 2007)
Targeted population: Human factors specialists working in

- Industry: 21
- Academia: 11
- Consultancy: 7

Questionnaire

1. Are you familiar with
   a. Process certification (e.g., ISO 9001 or other similar reference document)?
   b. Product design process incorporating human factors and ergonomics?
2. Do you think the defined requirements can help to develop ergonomic quality of products/services? If not, why?
3. Do you think this approach can help spread ergonomic knowledge among designers and the general public? "Helping people to make more informed decisions on ergonomic quality"? If not, why?
4. Overall, what kind of improvements do you suggest? In the approach? In the document?
5. As such, or with the modifications you recommend, would you be ready to use this kind of document to promote or to support your work?
6. Would you be able to integrate these ergonomic design criteria into existing product development processes? If not, what has to be improved to make this integration possible?
7. As such, or with the modifications you recommend, do you think this kind of document could be useful to someone else? What kind of person would you suggest?
8. Do you think these ergonomic design criteria are acceptable to product managers? Do you think they will understand these criteria will help to improve the global quality of their product?
9. Considering the format and the potential readers, i.e., people involved in product/service design:
   a. Do you think the size of the document is acceptable for communicating with most people?
   b. Do you think the document is easy to read? Any suggestions?

Main conclusions
- Positive judgments on the initiative and no major issue on content.
- Most critical views: from industry and consultancy.
- Major comments (from nearly half the respondents):
  - Improve overall readability of the document (hard to understand for a non-ergonomics expert, difficult for all who are not already familiar with ISO 9001, introduction particularly difficult to comprehend).
  - Usability and cost benefits aspects are not considered enough to convince product managers of the impact of ergonomics in design processes.

Second inquiry (EQUID template version 1.08, February 2008)
Targeted population: Product managers and industrial designers

- Product managers: 12
- Industrial designers: 7

- Functional managers: 4 (persons strongly involved in design processes)
- Industrial design professors: 3

Questionnaire

1. What is your profession?
2. Do you think the requirements defined in the EQUID design process can help to develop better quality products/services from an ergonomic viewpoint?
3. Do you think this document can help you better understand what to expect from professional ergonomists? Could it help anyone else in your organization?
4. Would you refer to this document in your professional activity? If not, why?
5. Do you think the requirements in this document could be clearly integrated into the design processes in your organization? If not, why?
6. Do you think the document (without the appendices, which are only provisional for now) is easy to read and the ideas are easy to communicate to your team?
7. What kind of improvements do you suggest in the overall message and in the document itself?

Main conclusions

- Although a qualitative inquiry, a majority of judgments support the document as useful and usable (a large majority of positive replies to questions 1–6 from all respondents).
- Some doubts and disagreements:
  - A few because some organizations have already implemented many of the stated requirements; these can be interpreted, to some extent, as positive judgments regarding the EQUID template.
  - A few people do not seem to be aware of the status and role of a reference document that shall have to be specified in each organization.

Document content and form

- Appendices:
  - Examples: a major effort must be made to produce forms/templates and short case studies in appendices.
  - More operational guidance adapted to application contexts (according to categories of products and services).
- Some more editing work needed (quality of the communication aspect is paramount!).

ANNEX 2 THE KEY REQUIREMENTS OF THE IEA EQUID PROCESS (PROVISIONAL VERSION)

1. Organization management and documentation

1.1 Management commitment

- Top management shall show evidence of its commitment to apply state-of-the-art rules and methods in ergonomics and ergonomic engineering.
- Top management shall communicate, throughout the organization, the importance of meeting the user requirements.
- Management has regular meetings to review the project and to consider questions of ergonomics.
- "Top management shall ensure that customer requirements are determined and are met with the aim of enhancing customer satisfaction" (ISO 9001:2008 §5.2).
- Top management shall document evidence of this (ways and means, decision reports).

1.2 Quality policy, quality objectives, and management planning

Top management shall:

- Document the ergonomic quality objectives and economic rationale for applying ergonomics in the design process.
- Set ergonomic quality objectives at relevant functions and levels. The objectives will consider the purpose of the organization. Ergonomic "quality objectives are measurable and consistent with the quality policy" (ISO 9001:2008, §5.4.1).
- Plan ergonomic tasks to meet the quality objectives. These main tasks are documented in
  - The "initial definition of the user requirements" (Part 2).
  - The "final ergonomic evaluation" (Part 4).
  - The after-sales "user satisfaction evaluations" (Part 5).
- Define the way the ergonomic inputs (mainly Parts 2, 4, and 5) are considered.
- Perform and document regular evaluations of the costs and benefits of the resource spent on ergonomics. This includes consideration of after-sales costs and user satisfaction.

1.3 Responsibility, authority, and communication

- Top management shall appoint a person to
  - Set up, carry out, and maintain state-of-the-art ergonomic practices.
  - Report to top management on ergonomic performance.
  - Communicate the ergonomic quality objectives within the organization.

1.4 Management reviews

- Management reviews shall regularly examine:
  - The user requirements (see 2.1).
  - Reports on ergonomic evaluations of test prototypes, if any (see 3.2).
  - Reports on final ergonomic evaluation before commercial delivery (see 4.1).
  - Reports from user satisfaction evaluations (see 5.1).
- At the beginning of the design process, management shall approve the definition of the initial requirements of users (Part 2).
- During the design process, management shall make decisions for corrective actions, to improve the product according to user requirements.
- Before the product is delivered, management shall consider the results from the final ergonomic evaluation. Management shall then make a decision whether to deliver or modify the product.
- Management shall make reports of all decisions in ergonomic matters.

1.5 Competence, awareness, and training of human resources

- A qualified ergonomist who has demonstrated ergonomic competencies relevant to the product design process shall participate regularly in the design process. The ergonomist shall supervise at least:
  - The initial definition of the user requirements (see 2.1) and any changes (see 2.2).
  - The final ergonomic evaluation (Part 4).
  - The after-sales user satisfaction evaluations (Part 5).
- Records are kept of the qualified ergonomist's education, training, skills, and experience.
- The qualified ergonomist may be part of the human resources of the organization, or external with a written contract of employment from the organization.

2. User Requirements document(s)

2.1 Initial user requirements document

User requirements shall include information that is necessary to help designers create innovative and ergonomic products. This information includes:

- The characteristics and the variation limits of the target users:
  - Categories of users (including secondary users), such as: age, gender, background knowledge, experience, and skills.
  - The variation limits around the "average user," i.e., users' descriptions shall cover all sorts of target users. These limits will be made clear to the public.
- The intended context of use, possible variation limits, and their effect on the user requirements:
  - Intended context and possible variation limits around the "normal" context.
  - The effect of this context on the user requirements.
- The goals of users, to be met by the product:
  - Activities of users, related to the product.
  - Factors influencing users when they do something with the product.
  - Typical usage situations showing possible difficulties of users and main variations.
  - "Normal use" variation limits and incorrect usage to be avoided.
- A description of the expected feelings users will experience when they use the product.
- User satisfaction reports on former versions of the product (see 5.1) or other similar products.
- Suggestions for solutions. These will be more detailed than standard guidelines.
- Performance criteria for the ergonomics of the product, including:
  - General criteria for typical use of the product (performance time, error rate, satisfaction, etc.).
  - Acceptable time limit to learn how to use the product.
  - A test plan for the ergonomics of the product. Show the targeted performance of the product for critical tasks.
  - Acceptance limits for the ergonomics of the product in a user test. This limit shall be set according to an initial evaluation plan.
- Relevant health and safety issues for users.
  - Applying standards or regulatory requirements (if any).
  - Criteria for comfort and health (minimize forces, repetitions, awkward and static postures).
- Planned after-sales help for users. User assistance information and the means to communicate that information.

The user requirements shall be clear and not in conflict with each other. When some requirements seem to contradict others, the contradiction and its explanation shall be clearly stated. Optional directions shall be given to solve the issue.

The user requirements shall be stated in a document. All persons involved in the design process can refer to this document. The document shall be easy to understand for all project partners and management representatives.

Notes:

- This document can be in any form: text, drawings, storyboards, videos, narrative scenarios, or a mix of these.
- This document will indicate directions for creative design. It will not be limited to authoritarian requirements, although some strict requirements may be necessary (e.g., safety issues or a few specific dimensions).

2.2 User requirements changes

- When any part of the initial definition of the user requirements is changed during the design process, the change shall be reported in the "User Requirements" document.

3. Design reviews

3.1 Design and development planning

Management shall:

- Plan ergonomic reviews according to the design and development stages.
- Plan ergonomic evaluations of intermediate samples of the product (if any).
- Make the responsibilities and authorities clear for decisions based on the ergonomic evaluations results.

3.2 Design and development reviews

- During regular reviews of design and development (see 1.4), report and discuss ergonomic issues to
  - Compare the results of intermediate ergonomic evaluations with the defined performance criteria for the ergonomics of the product (see 2.1 and 2.2).
  - Identify any problems.
  - Propose necessary actions.
  - Management shall make decisions on proposed actions.
- The organization shall keep records of the results of the reviews and decisions.
- The organization shall document what design review(s) is applicable for a particular product and, if applicable, reasons for not doing design reviews.

4. Final ergonomic evaluation report and management decision

4.1 Design and development validation

Management shall always:

- Validate ergonomic aspects of the product before delivering the product. "Design and development validation shall be performed in accordance with planned arrangements to ensure that the resulting product is capable of meeting the requirements for the specified application or intended use, where known. Wherever practicable, validation shall be completed prior to the delivery or implementation of the product. Records of the results of validation and any necessary actions shall be maintained" (ISO 9001:2008, §7.3.6).

Note: Verification based on checklists or expert inspection only is insufficient to validate the ergonomics of the product (see "ergonomic evaluation process" below).

- Perform ergonomic validation in reference to the defined user requirements (see 2.1 and 2.2). This validation shall include:
  - Controlling conformity with standards:
    - Complying with health and safety standards and the general safety obligation for consumer products.

    - Complying with relevant ergonomic standards (if not, give reasons).
    - Complying with relevant industry standards (if not, give reasons).
  - Completing the final ergonomic evaluation process. There are two documents to provide:
    - Before the evaluation, create a preparation document that includes:
      - Evaluation procedure, conditions, and user test scenarios.
        Note: Users' notices shall be considered as a part of the product.
      - Characteristics of the sample of test users.
      - Objective and subjective evidence to be collected.
      - Links to the user requirements (Part 2).
      - Conditions for a "go/no go" decision. Threshold for acceptance by users.
      - This shall be validated by management.
    - After the evaluation, create a final ergonomic evaluation report that includes:
      - Compliance with the definition of the requirements of users (Part 2). If not, it explains actions to take.
      - The possible effects on sales and after-sales costs in cases of no compliance.

Note: When a component or part of the final product comes from another organization, its possible effect on the ergonomics of the product shall be evaluated.

4.2 Management review of evaluation results compared to the user requirements

- Management shall perform a review before the organization commits to delivering the product to users. This evaluation shall include a discussion of the final ergonomic evaluation, which will help management make the "go/no go" decision.

5. User satisfaction evaluation reports

5.1 Monitoring and measuring after-sales user satisfaction

- Regularly, the organization shall collect and analyze data that gives information about:
  - After-sales user satisfaction and user complaints.
  - Whether the product complies with the definition of the user requirements (Part 2).
- The organization shall keep records of after-sales ergonomic issues and related costs and estimated benefits.

5.2 Control of a product that does not conform and corrective actions

- When a product does not comply with the user requirements, the organization shall eliminate the non-conformity. The organization "takes action to eliminate the cause of nonconformities in order to prevent recurrence: reviewing nonconformities (including customer complaints), determining the causes of nonconformities and reviewing corrective action taken" (ISO 9001:2008, §8.5.2).
- When an unintended use of the product risks the health and safety of users, the organization shall eliminate the non-conformity.
- If the correction of the non-conformity might affect the ergonomics of the product, the product shall be evaluated again after modification.

5.3 Monitoring and continual improvement

- The organization shall apply suitable methods for monitoring the ergonomic quality management, and continually improve its effectiveness through audit results, analysis of user satisfaction data, and corrective and preventive actions.

Section III

Digital Design

19 Behavior Video: A Methodology and Tool to Measure Human Behavior; Examples in Product Evaluation

Francisco Rebelo, Ernesto Filgueiras, and Marcelo M. Soares

CONTENTS

19.1 INTRODUCTION

The complexity of some newer product interaction in complex context systems demands a higher level of user performance and involves risk that may possibly negatively impact the user's safety and health. For this reason, the evaluation or design of new products used in complex systems requires extensive knowledge of human interaction, including the operation and vulnerabilities of the whole system. Therefore, with this consideration, the use of video analysis increases the capability to collect more detailed information on human activity during the interaction of the user with a product-environment system. With these data come increased understanding of user strategies and awareness of possible safety and health issues and system dysfunctions.

Video analysis has been used in many areas; especially in the sociology field that traditionally uses observation theory techniques (Kazmierczak et al. 2006; Spielholz et al. 2001; Strauss and Corbin 1990).

Recently, with the technological advancement of digital video equipment and computers, associated with low costs, video analysis is being routinely used in human behavior investigation. Video analysis usage makes multiple revisions possible, thereby allowing the collection of detailed information that would be impossible to collect in field studies involving only the researcher's visual memory. In this case, the use of a single source of observation (visual memory) may cause losses due to memory lapses and potential interpretation difficulties. It is, however, important to point out that for the ergonomist the exclusive use of video analysis is not a substitute for traditional tool usage in ergonomic analysis. In addition, some aspects, such as user interpersonal relations, environmental issues, and macro-ergonomic data, are also important in analyzing product quality. Video analysis allows the collection of human interaction data, such as the performance of a task associated with the worker's or user's cognitive strategies. According to sources (Mackenzie, Xiao, and Horst 2004; Neumann et al. 2001; Paquet, Punnett, and Buchholz 2001; Westbrook and Ampt 2008), video analysis usage involves:

- Where and when the problems related with security and the worker's health occur.
- How the individual differences lead to the problem resolution related with the work activity.
- How workers solve an emergency situation; highlighting the user's strategies and the capabilities of the equipment.
- How to identify the conditions in which mistakes and errors happen.
- The understanding of how workers react under stress.

Video analysis has also been used for auto-confrontation, such as workers vs. their real activities, task goals vs. workers execution of a task, and for the demonstration of one individual or group activity in training situations (Guerlain et al. 2004). Furthermore, it appears that in some situations no other data collection strategy can be used as effectively as video analysis.

The observation tools that use video are based on the definition of categories and are defined by the researcher. Some examples of these tools are the Actogram Kronos (Laperrière et al. 2006), Multimedia Video Task Analysis – MVTA (Dartt et al. 2009), and Observer XT (Convertino et al. 2009). Although these tools have considerable advantages in the study or evaluation of user behavior, it is important to call attention to the fact that the success of the analysis depends on the correct definition of the categories to be observed in the video. There is a tendency for professionals who use these traditional tools to commit errors in the definition of category observation when analyzing user behavior during the interaction with a product. Some people give up using these programs because the usability is poor.

However, the behavior video (BV) methodology defines the categories of observations, called categories of interactions, and the software to quantify them. The obtained results permit the ergonomist to evaluate user interactions with the product-environment in order to determine the quality of a product or provide data for the development of a new product.

The BV has been successfully used and evaluated in several situations either to develop or evaluate products, such as school furniture, computer and typewriter keyboards, and work systems for digestive endoscopic examinations. This chapter will detail an ergonomic product evaluation between the computer and typewriter keyboards.

19.2 BEHAVIOR VIDEO

The use of the BV comprises five distinct phases:

a. Analysis of reference situation
b. Definition of the categories of interaction
c. Video recorder of the user product–environment interaction
d. Register of the categories of interaction
e. Data analysis

Each phase will be explained in the following subsections.

19.2.1 Phase I: Analysis of Reference Situation

This phase refers to situations where the product is normally used in professional or leisure contexts. This approach is composed of four connected steps:

- Free observation: This situation refers to the context of use of the product, particularly the tasks, the environmental conditions, the relationship between other direct and indirect users, and the user *modus operandis*.
- Interviews/questionnaires: In these instances, information is obtained about user complaints; the problems that may occur using the product, and the environmental and organizational aspects that may influence the user's interaction with the product. This step is useful in data collection concerning user satisfaction with the product.
- Literature review: This phase comprises the collection and analysis of the available bibliographical and report references regarding problems during the use of the product and case studies with similar products.
- Problems diagnosis: This last step in Phase I is the identification of problems related to the product interaction under analysis. These problems are usually errors that may be responsible for accidents and/or the user's health problems, productivity, and efficiency. With the conclusion of this step, there should be a clear definition of the study objectives, including category definition of interactions and the time required to collect the data.

19.2.2 Phase II: Definition of the Categories of Interaction

The categories of interaction are pre-defined events that can be observed and can be a combination of task, posture, communication, displacement, handling, body movement cycle, field of vision, and/or hazard exposure, or a combination of these in order to create a new category.

(A) For instance, there could be two contexts with different probable problems that can be identified in an ergonomic analysis. In the first context, there can be an office situation where the workers complain about low back pain and productivity problems related to communications. In this situation, for example, the following interaction categories are proposed:

- Displacements in the office with heavy loads
- Seated posture without using the lumbar seat back support
- Seated with trunk torsion

- Talking on the telephone
- Talking with another person
- Talking with a specific person (e.g., a person of authority)

These categories can be combined to create a new one, for example:

- Displacements in the office with heavy loads and talking with another person
- Seated with trunk torsion and talking with another person
- Seated without the lumbar back support and talking with authority figure
- Seated talking on a telephone without using the lumbar seat support

(B) In another context related to automobile drivers and car accidents, the following interaction categories can be proposed, for example:

- Visual field related with the direction (in front, left or right) of the head to see information outside the vehicle
- Visual field related with the direction of the head (up or down) to see information inside the vehicle
- Adjust and turn on/off the car radio
- Move the torso from right to left and forward
- Communicating with the passengers
- An extra camera is needed to capture outside information regarding the traffic laws (e.g., stop sign, yield, etc.)
- Use of cell phones or the manipulation of other objects while driving

These categories may again be combined in order to obtain a new category, for example:

- Communicating with the passengers and not respecting the traffic laws
- Visual field related with the direction (in front, left or right) of the head to see information outside the vehicle and move the torso from right to left and forward
- Visual field related with the direction of the head (up or down) to see information inside the vehicle and to adjust and turn on/off the car radio

The analysis carried out with the support of the BV should consider the macro activity. This means that the definition of a category must be related to the grouping within the same time interaction and permits the measurement of a phenomenon that is suspect to constrain the system. It is also necessary to be aware of the classification of the categories in such a way as to avoid redundancies. However, this macro categorization depends on the objective of the analysis and the results of the ergonomic analysis carried out in Phase I (described above).

For each category of interaction it is helpful to complete a table with the following information:

- Name of the analyzed category.
- Objective for the category according to the focus of the study.
- Description of the video-recorded events that had determined the categories.
- The previous establishment of a hierarchy to combine all categories of interaction according to the objective of the study. This procedure when used will avoid eventual duplication of categories. In order to obtain a better visual comprehension of each phenomenon useful to a category classification, it is recommended that the images to be analyzed can be obtained directly from the video recorder. The video recording should occur after completion of Phase II and focus on user interaction with the product-environment elements.

It is important to note that the BV methodology permits the defining of twelve simultaneous categories.

19.2.3 Phase III: Video Record of the User Product–Environment Interaction

According to Cushman and Rosenberg (1991), products can be classified into two groups, consumer or commercial. This can influence the nature of the protocols regarding video recording of the user interactions with the product-environment. So, consider two types of video recorder protocols:

Protocol 1: Video record of a user manipulating a consumer product. The dutarion allowed to video record should be enough to record all possible observable task interactions with the consumer product.

Protocol 2: Video record of a worker manipulating a commercial product. The dutarion of recording depends on the objectives and the nature of the study. For ergonomic analysis, it is recommended to film during one day of work. However, when the task cycle is short or is only intended to analyze the task, the period of filming can be shortened.

It is important to state that those video recorder protocols are dependent on the results of the analysis of the reference situation (Phase I), the study objectives, and/or financial resources. When it is necessary to compare results, it is recommended to use statistic analysis to define the adequate samples (Sheskin 2004).

In an industrial or service situation, sometimes workers do not like to be filmed and people change their natural behavior when they know they are being observed. Therefore, an explanation and a time for familiarization with the process are necessary for the users of both the consumer and industrial products. The authors' experiences have shown that these situations can be avoided if

- An explanation is given to the subjects about the data recorder objective, preferably in a personal meeting, before the video recorder starts.
- The subject has a guarantee of confidentiality of the obtained images and that the results will not be included in the study in a way to personalize or identify the research subject.
- The subject must also sign a document authorizing the use of their images in the proposed study.
- All the maintenance procedures, such as changing video tapes, repositioning the camera, collecting the recorded tapes, etc., should be done without the presence of the subjects.

19.2.3.1 Regarding the Environment to Register the Images

The register of the image should be done in the real situation of use. When this is not possible, an environment simulation may be created where it is possible to observe all categories of interaction previously defined in a context adequate to the use of the product.

19.2.3.1.1 Regarding the Interference of the Observer

Burandt and Grandjean (1963) and Helander (2003) point out that the observer's presence may affect the way the subjects behave. Therefore, the following procedures are recommended to the video recorder:

- The cameras adjustment and maintenance should occur when the subjects are not present.
- If possible, the cameras may be dissimulated at the site to register the image in such a way that the subjects are not inconvenienced.
- If there is any feedback from the camera during the register process (e.g., a blinking light), it should be covered.

19.2.3.2 Regarding the Angles and Planes to Register the Image

The choice of angles to register the image must comprise the entire human figure interacting with the product. This is useful to visualize all movements of the human body. If possible, the video recorder should record the individual's image from the top of the head to the feet, including at least two image plans: frontal and lateral. These two image plans are useful to permit the easy identification of the categories of interactions. In some specific situations, such as with the use of video display terminals (VDTs), the frontal and lateral plans may reveal more details than other plans (e.g., superior).

19.2.3.3 Regarding the Number of Cameras to be Used

To video recording the work activity, one or more cameras may be positioned at strategic points in different plans. One camera can be used if it is possible to identify the categories of interactions without any difficulty. In other cases, the number of cameras used depends on the amount necessary to easily identify the defined categories of interactions to carry out the study. It is important to call attention to the necessity to synchronize the registered images with all the cameras. This synchronization must be done by two processes:

- Automatic synchronization: The video signal multiplexer (two channel) or video combiner doubles the transmission capacity of a conventional video channel by combining (multiplexing) the use of a digital system, which permits the connection and synchronization of two or more video cameras in a single image. The video multiplexer output can be viewed directly on a video monitor. The two, four, six, eight, or more video input channels appear side by side, with each being compressed to one-part of its original width in order to fit together in a normal size frame. Video inputs to the video multiplexer from analog tape or line-locked color cameras must be time base corrected. Some multiplexers have character generation in order to identify the cameras; a clock to register the recorder real time and detection of movements in order that the camera may turn on or off depending if there is anyone in the workplace.
- Manual synchronization: This approach may be used as an alternative to automatic synchronization. If this is the case, the event must be used to serve as a reference for two or more cameras; in the very start of the recording action (e.g., using a claket, lighting a lighter, or clapping hands).

19.2.3.4 Regarding the Type of Cameras

Any kind of camera independent of the object of video register, either a consumer product or a commercial product, can be used. However, due to the need for a continuum recorder during the whole period of analysis, it is recommended to use cameras that can register events for long periods and have a large storage capacity. It is also recommended to use wireless micro-cameras with night shot and a tripod when long periods of time are to be registered. The tripod should be fixed in the most convenient place to record the images in a way that also permits recordings even in bad illumination conditions.

19.2.4 Phase IV: Register of the Categories of Interaction

The register of the categories of interaction is done using a homonymous software (Behavior Video) especially developed to perform this task, which permits registration of the events and the moment of occurrence for each one of the twelve possible interaction categories.

Figure 19.1 shows a screen of the BV software where three areas can be identified:

- Control and information window: This area is where the video register can be controlled and shows the information related to the obtained data.
- Window to the selection of the categories of interactions: Up to twelve categories of interactions, represented by push button images, may be placed in this area. In Figure 19.1, it

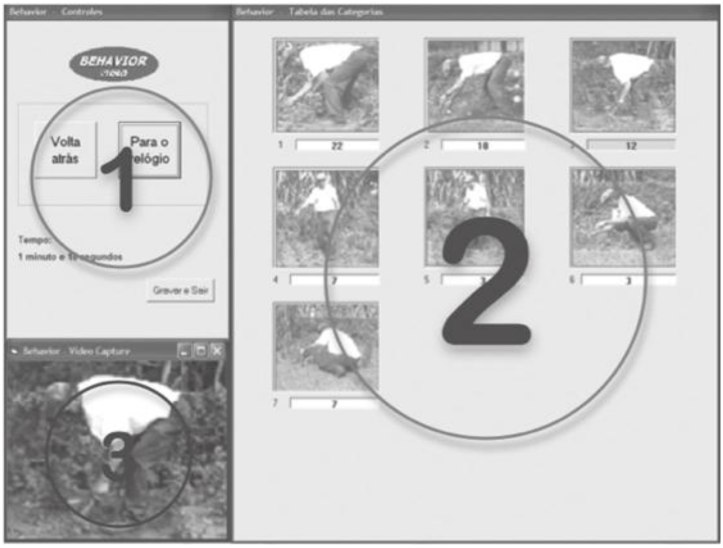


FIGURE 19.1 Behavior video screen: (1) control and information area, (2) window to the selection of the categories of interactions, and (3) window with the video recorder area.

can be seen that each image has its own identification number, the time of the event duration in seconds, and a visual activation feedback.

- Window with a video recorder area of the user interaction with product-environment situation: This can be a video capture from an analog video source using a video capture device.

Figure 19.2 shows an example of how to optimize the register of the categories using two monitors instead of only one (as shown in Figure 19.1). As can be seen in the left image, the worker's image fills the entire screen, while the right image shows the pre-classified categories.

In order to register the events related to the categories of information, the analyst should:

A. Start the video and allow enough time to decide which of the interaction categories correspond with the first event.
B. Rewind the video to the beginning and select the category of interaction (Figure 19.1, Window 2), identified in the previous phase. To select, it is necessary to click in the corresponding push button image.

FIGURE 19.2 The use of two monitors is mostly recommended to the register of the categories of interaction.

C. Play the video every time a new interaction category occurs. Then the observer selects the corresponding push button image. Automatically, the software saves the time spent and the moment of occurrence of each interaction category.
D. Correct any mistake, stop the video, return to the place where the error was made, and make a new classification.
E. Stop for pauses if needed.

The BV software may generate several reports at any time of data recovery. These include the following:

- Occurrence frequency of each observable category
- Total occurrence frequency of each observable category
- Moment of occurrence of each observable category

To avoid monotony and fatigue, the BV methodology recommends a pause of fifteen minutes for every hour of continuous analysis. These intervals provide visual rest and prevent overload of the analysis activity, which may influence the results obtained.

19.2.5 Phase V: Data Analysis

According to the objectives of the study, the data treatment must combine the results of the ergonomic analysis with the results of the BV methodology. This is useful to

- Identify the origin of the studied problems
- Provide useful information for the product redesign and design development
- Provide information for user training of commercial products
- Provide useful information for the design of a user's manual

19.3 EXAMPLES IN PRODUCT EVALUATION

The BV has been successfully used in several ergonomic studies. Froufe and Rebelo (2003) described a study justifying the use of new school furniture for children in their first four years of school. According to the study, twelve interaction categories were defined to evaluate the interaction categories of four students using school furniture during one week. The main conclusion of this study shows that students who spend 72% of their classroom time on writing and reading activities can develop postures responsible for musculoskeletal problems. The results of this study were recommendations useful in the design of new school furniture.

In another study, Filgueiras & Rebelo (2007) identified an inadequate office work organization, which resulted in workload problems due to lack of information shared by workers and managers. These results were based on a study using the BV with a sample of thirteen budget controllers' offices. Twelve categories of interaction were defined in the studies, e.g., computer data input, computer navigation, reading/writing, use of the calculator, use of the telephone, personal attendance, and when the person was away from the work station. The results showed that there are large differences in the workload at certain times of the month, which may be associated with the pressure by the management and the existence of many meetings. These may be considered the causes of the ineffectiveness of work performance.

The activity associated with the performance of digestive endoscopic examinations requires a high postural workload, which is associated with the layout of the workplace and the use of inadequate equipment (Cotrim et al. 2003). These results were demonstrated by the BV in a cross-sectional study of five volunteer endoscopists performing 53 upper video endoscopies and 36 video colonoscopies at a hospital's digestive endoscopy unit. Twelve categories of interactions were defined. The method included a complete videotaped record of all procedures with two cameras synchronized (anteroposterior and horizontal plans) in order to register twelve interaction categories of the subjects during the endoscopic examinations. The most important results showed that postures with cervical torsions were adopted 77% of the time and postures with cervical extension were adopted 28.8% of the time. These results are used for the development of ergonomic recommendations, namely, the re-conception of the endoscopic room layout and equipment design.

To illustrate the application of the BV methodology in this chapter, two products with similar objectives and different morphologies were chosen in order to evaluate the distribution of interaction behaviors while performing the same task. The chosen products are the typewriter and computer keyboard. Subsections 19.3.1 through 19.3.6 show the application of the BV in each of its five distinct phases.

19.3.1 Analysis of Reference Situation

According to the U.S. Census Bureau, in 1997 approximately 50% of all employed adults in the United States used a computer for their job. This report indicated that by the end of the last century, there was an extraordinary increase in the number of diseases and cumulative traumas in computerized work sites. (The number of cases is doubling each year.) Reports in the scientific literature and lay press have suggested that computer users are at increased risk of upper extremity musculoskeletal disorders (MSDs) and repetitive strain injury (RSI), also known as cumulative trauma disorder (CTD) (Dartt et al. 2009). In particular, researchers have found that interaction with computer devices is the main cause of MSDs/RSI/CTD (Bernaards et al. 2008; Hagberg et al. 2007). Generally, these studies have focused their attention on the computer keyboard, listing it as one of the devices responsible for the increase in these diseases. These studies found that the force applied to the keys, the postures assumed by the user, and especially the lack of breaks, has caused pain when working on the keyboard (Amell and Kumar 2000; Baker and Redfern 2005; Cook, Burgess-Limerick, and Chang 2000; Khalaf et al. 2007, Tittiranonda et al. 1999; Zecevic, Miller, and Harburn 2000).

The interaction with the computer and its peripherals, depending on the intensity and amount of use, is considered to be responsible for a number of occupational diseases. The most known harmful effects are musculoskeletal disorders related to postural constraints and to prolonged static activity, which aggravates, among other work diseases, RSI. However, as other activities are carried out, visual and phisiologycal disorders can also occur (Bernaards et al. 2008).

An analysis of the literature showed that few studies have compared the activity of typing on the computer with the activity of typing on manual typewriters. The few studies focused on details or on specific issues such as energy expenditure or the electrical response of the muscles involved in both tasks (Grandjean, Hünting, and Pidermann 1983; Kroemer 2001; Oborne 1995).

No studies were found in the literature associating manual typing on typewriters with the health issues of a professional typist. So, with this in mind, the hypothesis for this study is: Are there significant differences between the activities related to interaction with typewriters and keyboards? It is not the purpose of this chapter to answer this question, but to illustrate the use of the BV in the definition of the interaction categories and to evaluate differences in the activities with these two devices. The stages of this case study are described below.

19.3.2 Analysis of Reference Situations

In this situation the jobs were analyzed in two contexts, visits to offices where professionals use computer keyboards and visits to the homes of people who still use manual typewriters. Data were collected from questionnaires and interviews with the users of computer keyboards and the users of manual typewriters during the visits.

19.3.2.1 Free Observation

Free observation of the user's interaction with the products was not conducted in this case because of the contexts of the interaction and the main problems that typically occur are well known.

19.3.2.2 Interview

In order to gather information about the difficulties and the physical constraints of professional users of mechanical typewriters, twenty users of typewriters were chosen according to the following criteria:

A. Individuals who as professionals still use or have used the typewriter for at least 70% of the working day.
B. Individuals who currently use the computer keyboard in their daily activities and have worked with a typewriter in similar functions.

19.3.2.2.1 Interview Protocol

The interviews took place at the workplaces or the residences of the workers. The volunteers were initially contacted by telephone or e-mail and were scheduled a date for the interview and at the site of their choice. During the interview, the researcher encouraged an open discussion on the following topics:

- Positive and negative points for the use of typewriters.
- What professional circumstances forced them to use the typewriter for a long time?
- What were the main symptoms that felt painful during prolonged use of such equipment?
- How many co-workers recalled temporarily stopping work due to problems in the joints of the upper limb?
- What symptoms or problems were believed to be related to prolonged use of the typewriter?

19.3.2.2.2 Interview Results

Only the results necessary to understanding the BV methodology are presented:

- Seventy percent of respondents said they used the typewriter for more than six hours of daily work.
- Sixty percent of respondents identified back pain as the main problem derived from occupational overuse of the typewriter. However, they do not know of any colleague who failed to come to work due to symptoms related to MSDs/RSI/CTD.

The results of this interview were used to help in the development of a questionnaire to clarify doubts about the initial activity with the typewriter in their work contexts, particularly about the problems of MSDs/RSI/CTD and other constraints affecting old and new users of the typewriter and keyboards.

19.3.2.3 Questionnaire

The questionnaire sample included thirty typists and thirty computer users distributed into two profiles:

- *Profile A:* Subjects aged between 18 and 30 years (average 26) who work at typing information using a computer keyboard for more than two-thirds of their work activity and more than six hours daily.
- *Profile B:* Subjects aged 40 and above (average 45) who have worked for many years typing information using a typewriter for more than two-thirds of their present or previous

activities and more than six hours daily. In this profile, these subjects are currently using a computer keyboard for more than two-thirds of their work activity. Only three subjects—two journalists and a secretary—that belonged to Profile B, still work with typewriters.

19.3.2.3.1 Composition of the Measuring Instrument

The researchers developed and validated a questionnaire with twenty-seven questions adapted from the previous user profiles. Sixty-three participants responded to the questionnaire and participated in the three pilot tests using the Cloze Test (Taylor 1953). The participants scored approximately 76% on the Cloze Test, which measures the comprehension of the reading material.

The questions used in each of the studied profiles (computer and typewriter) were almost identical and had the same purpose. The only difference was the verb tense used in each question because of the need to establish the chronology of events; for Profile A (computer) "Do you know of any work colleague who has a problem using the keyboard?" for Profile B (typewriter) "Do you know of any work colleague who had a problem using the typewriter?" These two verb tenses referred to the time interval that separates the users of computer keyboards and the users of typewriters.

To get information about the pain or discomfort felt while typing during a day of intense work, the user should select an area from the image of the human body, mapped to twenty-eight regions and adapted from the body map (Corlett and Bishop 1976).

19.3.2.3.2 Main Results of the Questionnaire

Although the researchers used sixty questionnaires, the results cannot be interpreted as representative of a whole population, but as a random sample of this exploratory research. Structured surveys with the target population were applied using the BV methodology. In this work, we present only the most important results for the BV.

In Profile A, the results of the questions regarding pain or discomfort felt during typing showed that the primary complaint was the right hand (13.7%), followed by the trapezium (11.2%), the lumbar zone (10.2%), and the cervical region (8.7%). The others regions cited did not exceed 1.7% of the complaints. The head region received the most complaints (15.4%) followed by the right hand (11.5%). An important lesson drawn from these data showed that in Profile A all twenty-eight regions of the body were marked, but in Profile B, thirteen of the twenty-eight regions were marked.

19.3.2.4 Diagnosis of the Situation Problems

In summary, it was found that the data results from the questionnaire and interviews confirmed the findings in the literature on MSDs/RSI/CTD by other authors regarding the complaints related to the use of keyboards in work situations. The data point to a rising number of cases of diseases related to VDTs.

Several studies have revealed a variety of factors that contribute to the growing problems and the main reason for the decrease in the performance of office workers. Among them can be highlighted: the increase in working hours on a computer (Baker and Redfern 2005), the increase in psychological stress levels due to an increase in the cognitive demands of the workers (Bongers et al. 1993; Faucett and Rempel 1994), and a lack of requirements and ergonomic-specific characteristics of the workstations (Carayon and Smith 2000; Nelson and Silverstein 1998). Some authors also point to other epidemiology issues associated with the use of keyboards and computers (Gerr, Marcus, and Monteilh 2004).

19.3.3 Definition of the Categories of Interaction

Considering the data obtained in the previous phases, the objectives of this study and the need to perform an overall analysis of the behavior of interaction, the authors defined twenty-three typical interaction categories: eleven for the keyboard and twelve for the typewriter (see Table 19.1).

TABLE 19.1
Categories of Interactions for the Typewriter and the Computer Keyboard

Typewriter			Keyboard		
Category		Description	Category		Description
Action Group	No.		Action Group	No.	
Typewriting	1	Looking at the keys	Typing	1	Looking at the keyboard
	2	Looking at the document in the typewriter		2	Looking at the screen
	3	Looking at the source document		3	Looking at the source document
Not typewriting	4	Moving typewriter carriage	Not typing	4	Using the mouse
	5	Passing the page on the source document		5	Passing the page on the source document
	6	Reading the text in the source		6	Reading document in the source
	7	Reading document on the typewriter		7	Reading document on screen
Pause main action	8	Setup the workstation	Pause in main action	8	Setup the workstation
	9	Looking for help		9	Looking for help
	10	Stretching		10	Stretching
	11	Changing the paper in the typewriter		11	Out of the workstation
	12	Out of the workstation			

In order to facilitate the identification of the interaction categories, they were organized into three groups for the typewriter and computer keyboards:

- Group A: Typewriting—the user interacts with the keys of the typewriter or the computer keyboard to type the selected character (categories 1–3).
- Group B: Not typewriting—in a productive activity such as reading, writing, etc. At the typewriter (categories 4–9); at the keyboard (categories 4–8).
- Group C: Pauses at the workstation—non-productive activity not related to the work task. At the typewriter (categories 10–12); at the keyboard (categories 9–11).

The interaction moments and the small changes in behavior that belong to the same category were detailed for each one of these categories. Then, three images representing the different behaviors within the same scenario were selected (see Figure 19.3).

19.3.4 Video Recorder of the User Product–Environment Interaction

The criteria for selecting the sample for this study phase:

- Having worked with a mechanical typewriter for more than six hours daily
- Still using a mechanical typewriter for at least one-fifth of the time in their current occupation
- Knowing and currently working with keyboards for at least two-thirds of their daily working hours
- Typing using a typewriter and typing using a keyboard
- Good health with no evidence of occupational diseases in the upper limbs
- Knowing the mechanisms of the typewriter and keyboard

19.3.4.1 Equipment used in the Experiment

The requirements for the typewriter were

A. In good working condition
B. Used for professional activity
C. Typewriter (not a collector's piece or ready to be abandoned)

Detail keyboard–category 11		
Description: Category triggered when the subject extends any region of the body or demonstrates any act of fatigue as eye rubbing or stretching the neck, arms, and torso.		
Image A	**Image B**	**Image C**
		
Rub their eyes	Stretching the neck	Stretching the arms and torso

FIGURE 19.3 Breakdown of three major behaviors from category 11 at the keyboard.

The requirements for the keyboard were

A. Classified as a standard keyboard, without any special resources, such as ergonomic adaptations or hybrids (with mouse, special shortcut keys, etc.)
B. Following the Brazilian norms
C. Used in a personal or professional environment

These requirements guaranteed that the selected products were, in fact, used in the work activity. Before the test, the participant kept the typewriter for a three-day familiarization process with the product. There was not the same need for the keyboard because this product belonged to the participant.

The authors used a Sony DCR-SR220 digital camera with 25 frames per second on a tripod positioned six meters from the individual. No special features of the camera were used during the recording process.

19.3.4.2 Filmed Environment

The images were collected in the volunteer's workplace. The tests were performed on two different days of the same week, with a three days pause in between. The schedule was established by the volunteer.

In order to prevent the interference of other stressing factors in the results, the volunteer was instructed not to perform any personal or business activities involving a physical or psychological burden before the recording day. The volunteer was also asked to notify the researcher of any physical symptoms or professional concerns before the collection of images.

19.3.4.3 Collection Procedures

The collection of images took four continuous hours for each one of the activities—using a computer keyboard and a typewriter (eight hours total) with intervals of 96 hours between them. The participant was instructed to stop when he felt tired or when needed. The experiment was carried out in the participant's own office and the workstation was adjusted by him in a way that better attended his needs. The volunteers could stop the activity only under two conditions; physiological reasons and/or to clarify doubts about the test.

19.3.4.4 Selection of the Texts used for the Tests

According to Moraes (1995), in order to maintain the same conditions of readability in two or more texts used in scientific studies, it is strongly recommended that the source be the same and gives preference to contents of general knowledge. Owing to the duration of this test, the contents of the two texts should be long enough to avoid interruptions. To this end, before the test we randomly selected two texts with 230 pages each, belonging to the Encyclopedia Britannica. However, during the choice of texts, the researchers were concerned about excluding non-familiar content in order to prevent difficulties with the comprehension of terms, thereby avoiding unnecessary interruptions and increasing the volunteer's attention to the task.

19.3.5 Register of the Categories of Interaction

The register of the categories of interaction on the BV was accomplished according to the pause recommendations already described in Section 19.2.4. Thus, eight hours of video register (four for each device) took 12 hours to be registered and analyzed by the BV (including the pauses spent by the ergonomist while collecting the information.).

19.3.6 Data Analysis

The purpose of this example was to show the application of the BV in the evaluation of these two similar products. In this context, only general results relevant to the analysis of the comprehension

TABLE 19.2
Main Results of BV Interactions on a Typewriter Machine

Occurrence Frequency (%)	Action Group	Category No.	Description
• 50.44	Typewriting	3	Looking at the source document
• 14.12		2	Looking at the document in the typewriter
• 12.16		1	Looking at the keys
• 6.57	Not typewriting	4	Moving typewriter carriage
• 6.28		11	Changing the paper in the typewriter
• 2.27		6	Reading the text in the source
• 2.14	Pause in main action	8	Setup the workstation
• 9.08	Not typewriting/pause main action	5, 7, 9, 10	Others less than 2%

of human behavior during the interaction with a product-environment system are presented. It should be noted that the specific results will be discussed in a forthcoming publication.

Table 19.2 introduces the frequency of occurrences of each category for the twelve typewriter machine interaction categories (see left-hand side of Table 19.1), with the exception of the category "out of the workstation" (for more about the register of the categories of interactions, see Section 19.2.4). It is important to note that the categories with few occurrences (categories 7, 8, 9, and 10) are grouped in the last row of the table.

In a similar way, Table 19.3 introduces the frequency of occurrences of each category for the eleven keyboard interaction categories (see Table 19.1) with the exception of the category "out of the workstation." The categories with few occurrences are also grouped in the last row of the table (categories 7, 8, 9, and 10).

The result of this study has shown that there are many similarities in the operating procedure of the typewriter machine and the computer keyboard in the category "typing." However, some disparity was found in the item "no typing." Most of these divergences occurred between the keyboard category 4 "using the mouse" and the typewriter categories 4, 6, and 11, respectively, "moving typewriter carriage," "reading the text in the source," and "changing the paper in the typewriter" (Tables 19.2 and 19.3).

Another consideration that should be taken into account is a comparison of the groups of activities named "not typewriting," for the typewriting machine and "not typing" for the keyboard (see Tables 19.2 and 19.3). The first one shows that the sum of three frequencies of the not typewriting activities: "moving typewriter carriage," "changing the paper in the typewriter," and "reading the text in the source" is 15.12%. On the other hand, the sum of the three frequencies of

TABLE 19.3
Main Results of BV Interactions on Computer Keyboard

Occurrence Frequency (%)	Action Group	Category No.	Description
• 41.82	Typing	3	Looking at the source document
• 11.61		2	Looking at the screen
• 11.49		1	Looking at the keyboard
• 17.05	Not typing	4	Using the mouse
• 3.23		6	Reading document in the source
• 2.44		5	Passing the page on the source document
• 12.34	Not typing/pause main action	7, 8, 9,10	Others less than 2%

the not typing activities: "using the mouse," "reading document in the source," and "passing the page on the source document" is 22.72%. However, it should be noted that the activity "using the mouse" alone is responsible for the vast percentage of the time spent in the whole activity (17.05% out of 22.72%).

Some lessons have emerged from the comparison of these two devices using the BV that would not be possible with traditional ergonomic methods:

- The sum of the frequency of the time spent in the categories "typewriting" and "typing" shows that the category "typewriting" is approximately 15% higher than the category "typing" (Tables 19.2 and 19.3).
- The sum of the frequency of the time spent in the categories "not typewriting" and "not typing" shows that the category "not typewriting" is approximately 33% higher than the category "typing" (Tables 19.2 and 19.3).
- Some authors, such as Oborne (1995) and Grandjean (1983), pointed out that the sum of actions spent on the typewriter machine are higher, which means that users may interrupt their activities several times while using the typewriter. The reason may be that the activities of typing from the biomechanical point of view are very demanding. According to these authors, the micro pauses may bring rest to the finger articulations involving the typewriting activity. This study has shown that the "not typewriting" action group, e.g., activity 4 "moving typewriter carriage" and activity 11 "changing the paper in the typewriter," are carried out in less time than the "not typing" action group, e.g., activity 4 "using the mouse."
- Summarizing: The time of interaction by the user when he uses the keyboard is less than the time of user interaction when he uses the typewriter for the same activity. However, the time spent by the user when he uses the keyboard with other activities, classified as not typing, represents more time for resting when using the keyboard than the typewriter.

The result of the data analysis concludes that the activities of typewriting and typing are more similar than it was presumed. However, due to the small sample of this study, it is not possible to conclude that the activity of typewriting is more demanding than the activity of typing, regarding the number of pauses carried out in both activities.

19.4 DISCUSSION AND CONCLUSIONS

In this chapter, a methodology based on a computer program was revealed to understand the user interaction with the product-environment system. This method is compatible and complementary to an ergonomic analysis as it uses tools with the same purposes in the first phase of the study, e.g., free observation, interviews, and questionnaires. In this regard, for the successful implementation of the BV, it is necessary to know and understand the main difficulties and other problems encountered by potential users with the interaction of the product and the environment. This process will allow the definition of consistent study objectives, which lead to the definition of categories of interaction for understanding the user interaction problems related to the product.

The BV methodology and the software were developed exclusively from an ergonomic approach to analyze the work situation or interaction of consumer and commercial products from a broader perspective (macro analysis). Thus, the BV is not efficient in the evaluation of greater precision activities, such as the accurate recording of the angles of a segment (micro analysis). The use of traditional tools found in occupational biomechanics, such as goniometry, cinemetry, etc. (Chaffin and Andersson 1991) is recommended in these situations.

The advantages of the application of the BV in product evaluation or design can be summarized as follows:

- Allows a detailed understanding of the interaction of equipment with the environment and to find plausible explanations for the problems in elements of this interaction.
- During the development of the product, it allows the designer to develop and justify the solutions based on the specific user needs and on understanding the problems during the user interaction with the product and the environment.
- By highlighting eventual problems of a poorly designed product, the data collected by the BV will permit the development of more efficient user manuals.

However, BV has several constraints that were and continue to be addressed and revised, namely:

- Because there are no pre-classified categories for each product and context of interaction, the BV requires an analysis developed by a professional to define those categories of interaction.
- If the initial stage "analysis of reference situation" of this methodology is not well done, there will be difficulties during the process of defining the categories of interaction.
- An analysis with the BV has time and financial costs, so it cannot be justified in some ergonomic intervention business projects or in the development of products with low complexity user interaction. In view of this, it might be more appropriate for the BV when there is a suspicion that the product prototype is difficult to use or in research.
- Unlike the various tools and methodologies in an ergonomic analysis that already exist, the BV does not culminate with a probable diagnosis or levels of severity for the observed events. The BV is able to provide detailed, relevant information and consistent data so that professionals can make a more accurate diagnosis rather than provide the diagnosis.
- Due to the complexity of the analysis of the interaction categories developed from the results of the BV methodology, an experienced professional ergonomist is required to conduct the work.

In conclusion, BV methodology has made it possible to obtain important data for the ergonomic diagnosis of a particular situation of interaction that would hardly be obtained by traditional methods, such as the case study reported here. BV methodology is thus an important tool for the evaluation of products and the environment in real use contexts and for the information obtained about the product and/or system quality.

REFERENCES

Amell, T., and Kumar, S. 2000. Cumulative trauma disorders and keyboarding work. *International Journal of Industrial Ergonomics* 25 (1): 69–78.

Baker, N.B., and Redfern, M.S. 2005. Developing an observational instrument to evaluate personal computer keyboarding style. *Applied Ergonomics* 36:345–54.

Bernaards, C., Ariëns, G., Simons, M., Knol, D., and Hildebrandt, V. 2008. Improving work style behavior in computer workers with neck and upper limb symptoms. *Journal of Occupational Rehabilitation* 18 (1): 87–101.

Bongers, P.M., de Winter, C.R., Kompier, M.A., and Hildebrandt, V.H. 1993. Psychosocial factors at work and musculoskeletal disease. *Scandinavian Journal of Work, Environment & Health* 19 (5): 297–312.

Burandt, U., and Grandjean, E. 1963. Sitting habits of office employees. *Ergonomics* 6 (2): 217–28.

Carayon, P., and Smith, M.J. 2000. Work organization and ergonomics. *Applied Ergonomics* 31 (6): 649–62.

Chaffin, B., and Andersson, D.G. 1991. *Occupational Biomechanics*. New York: Wiley-Interscience.

Convertino, G., Mentis, H. M., Rosson, M. B., Slavkovic, A., & Carroll, J. M. (2009). Supporting content and process common ground in computer-supported teamwork. Proceedings of the 27th international conference on Human factors in computing systems CHI 09, (1), 2339. ACM Press. Retrieved from http://portal.acm.org/citation.cfm?doid=1518701.1519059.

Cotrim, T., Francisco, C., Freitas, J.L., Fonseca, M., Rebelo, F., and Barreiros, B. 2003. An ergonomic evaluation of endoscopic examinations: Formulation of guidelines to improve the interactions between physicians and equipments. *Proceedings of XVth Triennial Congress of International Ergonomics Association,* Seoul, South Korea.

Cook, C., Burgess-Limerick, R., and Chang, S. 2000. The prevalence of neck and upper extremity musculoskeletal symptoms in computer mouse users. *International Journal of Industrial Ergonomics* 26 (3): 347–56.
Corlett, E., and Bishop, R. 1976. A technique for assessing postural discomfort. *Ergonomics* 19 (2): 175–82.
Cushman, W., and Rosenberg, J. 1991 *Human Factors in Product Design.* Amsterdam: Elsevier.
Dartt, A., Rosecrance, J., Gerr, F., and Chen, P. 2009. Reliability of assessing upper limb postures among workers performing manufacturing tasks. *Applied Ergonomics* 40:371–78.
Faucett, J., and Rempel, D. 1994. VDT-related musculoskeletal symptoms: Interactions between work posture and psychosocial work factors. *American Journal of Industrial Medicine* 26:597–612.
Filgueiras, E., & Rebelo, F. (2007). An interactive system to measure the human behaviour: an analysis model for the human-product-environment interaction. Paper presented at the Proceedings of the 2007 international conference on Ergonomics and health aspects of work with computers.
Froufe, T., and Rebelo, F. 2003. Evaluation and development of a new concept of school furniture. *Proceedings of the International Ergonomics Association,* Seoul, South Korea.
Gerr, F., Marcus, M., and Monteilh, C. 2004. Epidemiology of musculoskeletal disorders among computer users: Lesson learned from the role of posture and keyboard use. *Journal of Electromyography and Kinesiology* 14:25–31.
Grandjean, E., Hünting, W., and Pidermann, M. 1983. VDT workstation design: Preferred settings and their effects. *Human Factors* 25 (2): 161–75.
Guerlain, S., Turrentine, B., Adams, R., and Calland, J. 2004. Using video data for the analysis and training of medical personnel. *Cognition, Technology & Work* 6 (3): 131–38.
Helander, M. 2003. Forget about ergonomics in chair design? Focus on aesthetics and comfort! *Ergonomics* 46 (13/14): 1306–19.
Kazmierczak, K., Mathiassen, S., Neumann, P., and Winkel, J. 2006. Observer reliability of industrial activity analysis based on video recordings. *International Journal of Industrial Ergonomics* 36 (3): 275–82.
Kroemer, K. 2001. Keyboards and keying: An annotated bibliography of the literature from 1878 to 1999. *Universal Access in the Information Society* 1:99–160.
Laperrière, E., Ngomo, S., Thibault, M., and Messing, K. 2006. Indicators for choosing an optimal mix of major working postures. *Applied Ergonomics* 37:349–57.
Mackenzie, C., Xiao, Y., and Horst, R. 2004. Video task analysis in high performance teams. *Cognition, Technology & Work* 6 (3): 39–147.
Moraes, A. 1996. Legibility of texts in video display interfaces. In: Proceedings of the Silicon Valley Ergonomics Conference & Exposition Ergocon '96, 67–71. Palo Alto, California, San Jose State University.
Nelson, N.A., and Silverstein, B.A. 1998. Workplace changes associated with a reduction in musculoskeletal symptoms in office workers. *Human Factors* 40 (2): 337–50.
Neumann, W., Wells, R., Norman, R., Kerr, M., Frank, J., and Shannon, H. 2001. Trunk posture: Reliability, accuracy, and risk estimates for low back pain from a video based assessment method. *International Journal of Industrial Ergonomics* 28 (6): 355–65.
Oborne, D.J. 1995. *Ergonomics at Work: Human Factors in Design and Development*. Chichester: John Wiley.
Paquet, V., Punnett, L., and Buchholz, B. 2001. Validity of fixed-interval observations for postural assessment in construction work. *Applied Ergonomics* 32:215–24.
Sheskin, D. 2004. Handbook of Parametric and Nonparametric Statistical Procedures (3rd ed.), by David J. SHESKIN, 1193. Boca Raton, FL: Chapman & Hall/CRC, 2004, ISBN 1-58488-440-1.
Spielholz, P., Silverstein, B., Morgan, M., Checkoway, H., and Kaufman, J. 2001. Comparison of self-report, video observation and direct measurement methods for upper extremity musculoskeletal disorder physical risk factors. *Ergonomics* 44 (6): 588–613.
Strauss, A., and Corbin, J. 1990. *Basics of Qualitative Research: Grounded Theory, Procedures, and Techniques*. Newbury Park, NJ: Sage.
Taylor, W.L. 1953. Cloze procedure: A new tool for measuring readability. *Journalism Quarterly* 30, 415–33.
Tittiranonda, P., Rempel, D., Armstrong, T., and Burastero, S. 1999. Effect of four computer keyboards in computer users with upper extremity musculoskeletal disorders. *American Journal of Industrial Medicine* 33:647–61.
Westbrook, J., and Ampt, A. 2009. Design, application and testing of the Work Observation Method by Activity Timing (WOMBAT) to measure clinicians' patterns of work and communication. *International Journal of Medical Informatics* 78:25–33.
Zecevic, A., Miller, D.I., and Harburn, K.L. 2000. An evaluation of the ergonomics of three computer keyboards. *Ergonomics* 43 (1): 55–72.

20 Digital Human Modeling in the User-Centered Design Process

Stephen J. Summerskill and Russell Marshall

CONTENTS

20.1 INTRODUCTION

The process of designing products has changed drastically over the past 20 years, with an increasing reliance on virtual processes such as computer-aided design (CAD) software. CAD software provides designers and engineers with tools that allow the production of virtual parts that are highly accurate in terms of geometric and visual representation. Automotive manufacturers, who benefit from the ability to accurately model the thousands of parts that interact to produce an automobile, have embraced these powerful tools. The virtual automotive design process has reduced the need for physical mock-ups that were traditionally produced to support the engineering design process. A negative side effect of this is that the user testing opportunities that were afforded by the production of these mock-ups have also been reduced. The ability to perform user testing early in the design process has many potential benefits in terms of the identification of issues of fit, control layout, and safety. An added benefit of early user testing is that the issues that are identified can be solved before the majority of the vehicle has been designed. This avoids the costly redesign of parts that are associated with fixing errors that are identified through later user testing.

It is now common practice among automotive manufacturers to use digital human modeling (DHM) systems to replace the early user testing that was traditionally performed with real people. DHM systems provide the designer or engineer with CAD-based virtual people that can be changed in size, and postured to replicate human activity. DHM systems can therefore be used to assess issues such as seat adjustability ranges, reach to controls, and vision of displays, using the same CAD data that are used to manufacture parts.

The following chapter has been produced by members of the Design Ergonomics Research Group (DERG) based in the Department of Design and Technology at Loughborough University in the UK. The DERG has a long history of developing and applying DHM systems to the design of vehicles. Through interaction with a number of automotive manufacturers, and attendance at conferences that focus on the use of DHM, it has been noted that there is the potential for the capabilities of DHM to be exaggerated. For example, DHM systems are used to simulate the task of entering a car. The task of entering a vehicle is dependent on a number of variables, such as body size and shape, muscle strength, joint flexibility, and individual behavior. The data on the variability of joint motion, force application ability, and behavior used by current DHM systems are not sufficiently detailed to allow an accurate prediction of how a person will get into or out of a car, especially when one considers the simulation of the abilities of elderly people, for which there is little data available. This highlights that it is important for the users to be aware of the limitations of the data that drive DHM systems. The following chapter describes the structure of DHM systems, the data that drive them and the challenges in the use of the data that are often overlooked. This is followed by a case study that demonstrates how a DHM system can be used to perform an analysis of a car interior as part of a human-centered design approach.

20.1.1 Digital Human Modeling

20.1.1.1 What is Digital Human Modeling?

Digital human models/modeling is a phrase used for software systems that allow the creation of articulated 3D human models, in a CAD environment (see Figure 20.1). These DHMs can then be used to perform evaluations of a CAD model of an existing or proposed workstation design. In this context, workstation is used to represent any product or environment that a human may interact with. A typical example of an evaluation performed using a DHM system would be the automotive interior package, including the seat, steering wheel and other controls, interior bodywork, etc. An example of this process can be seen in Section 20.4, which presents a case study of this kind of evaluation.

The exact capability of a DHM system in performing an evaluation will vary from system to system, but generically they share the ability to evaluate the fit, posture, reach, and vision of human models sized to represent people within a specific national population. Typically, by using a range of DHMs to explore the limits of a single or multiple populations, conclusions can be drawn about the ability of the product or environment being investigated to accommodate that population.

DHMs are able to interact with CAD models of workstation designs by having the ability to change posture, enabling the assessment of control reach-ability and visibility. In this way, workstations can be assessed for fit before they ever take physical form, reducing the need to build expensive prototypes and enabling a rapid iterative problem-solving design process. However, DHMs are not replacements for physical mock-ups and user trials with real people. Their benefit is in establishing an accessible and accommodating design early in the development process while changes can be made easily and cheaply. At this stage, alternatives can easily be explored and the issues fully understood. At an appropriate point, when the design is reasonably mature, user trials can be conducted to

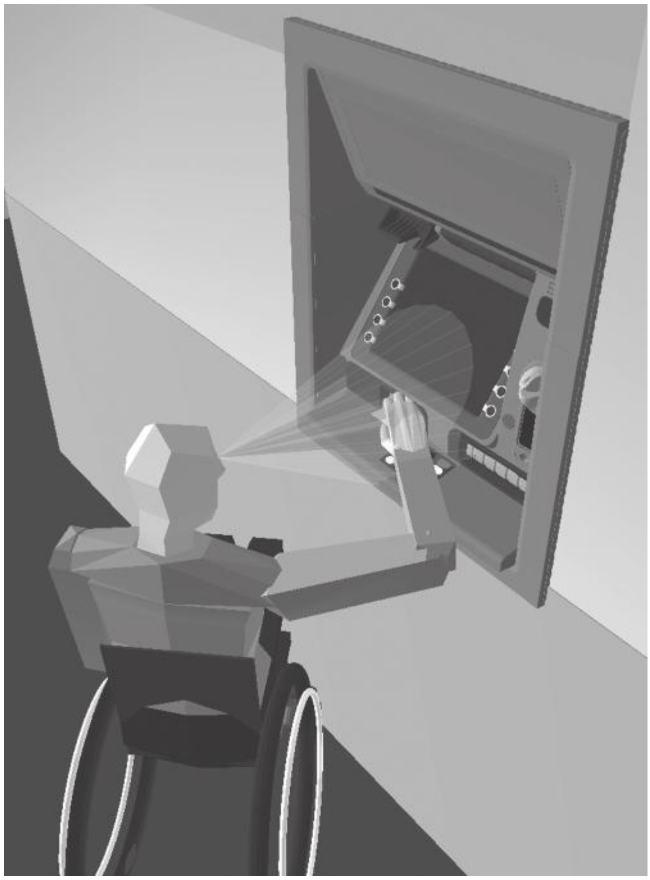


FIGURE 20.1 An image of a typical digital human modeling system.

elicit the rich data provided by real people, including feedback on comfort, and other cognitive and emotional issues, the analysis of which are currently lacking in DHM systems.

The capabilities of DHM systems to simulate human movement, vision, and size variability make them powerful tools in the development of products and environments. DHM systems are currently used to analyze a wide range of design problems. There are currently a number of different DHM systems available to the user.

20.1.1.2 Digital Human Modeling Systems

This chapter is largely based around the experience of development and use by the authors of one particular DHM system, namely SAMMIE (Porter et al. 2004; SAMMIE CAD 2010). SAMMIE (System for Aiding Man Machine Interaction Evaluation) is a DHM system that has been in development and used for the past 40 years (see Figure 20.2). Since its conception, SAMMIE has been continuously employed in research and as a consultancy tool (Porter, Case, and Freer 1996, 2009). In addition, SAMMIE CAD, the company that develops the SAMMIE system, has operated as an ergonomics design consultancy since 1985 and has completed some 300 commercial projects for over 80 national and international clients. This section is based on the experience gained through the development and exploitation of the SAMMIE system to highlight some of the fundamental issues with DHM and details the SAMMIE team's approach to supporting the use of computer-aided ergonomics throughout the product development process.

Evidence suggests that DHM is becoming increasingly sophisticated and its use ever more widespread. Initially, DHM systems, such as SAMMIE, were largely regarded as applications of

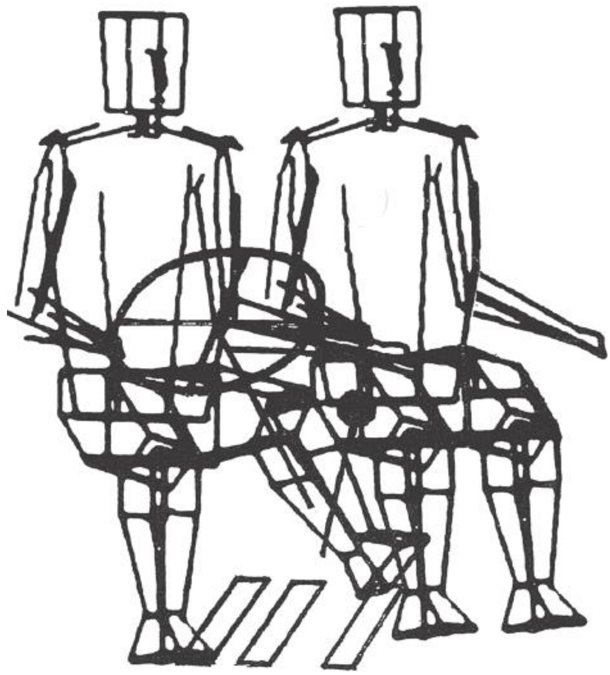


FIGURE 20.2 An early image of the SAMMIE DHM system circa 1970.

computer graphics, essentially a human-object visualization tool. Unfortunately, this enthusiasm was not matched by an equal commitment to the application of ergonomics (Porter, Case, and Freer 1996). Today, the situation is largely reversed with ergonomics becoming recognized as an essential element of the design process, though the visualization element is still a strong and useful element in the use of DHM systems. In addition, DHM systems are also now the subject of international standards that present detail on DHM system requirements and their accuracy (BS EN ISO 15536-1 2008; BS EN ISO 15536-2 2007).

Throughout the history of DHM there have been many DHM systems all with their own representation of the human form and set of tools to aid in ergonomics evaluations. Such systems include: ADAPS (Delft University, The Netherlands, see Post and Smeets 1981), ANYBODY and ANTHROPOS (IST GmbH, Germany), APOLIN (Grobelny et al. 1992), BOEMAN (Boeing Co., USA), BUFORD (Rockwell International, USA), CAR (Naval Air Development Centre, USA), COMBIMAN and CREW CHIEF (Armstrong Aerospace Medical Research Laboratory, USA, see McDaniel 1990), CYBERMAN (Chrysler Co., USA), Deneb/ERGO (USA), ERGODATA (Laboratoire d'Anthropologie Appliquee, France) and ERGOMAN (see Coblenz, Mollard, and Renaud 1991; LAA 2010), ergoSHAPE (Institute of Occupational Health, Finland), ergoSPACE (Institute of Occupational Health, Finland, see Launis and Lehtelä 1990), FRANKY (G.I.T., Germany, see Elias and Lux 1986), JACK (initially University of Pennsylvania, now part of Siemens PLM, see Badler, Phillips, and Webber 1993; Siemens 2010), MDHMS (McDonnell Douglas, USA), ManneQuinPRO/HumanCAD (NexGen Ergonomics Inc. 2010), MINTAC (Kuopio Regional Institute of Occupational Health and the University of Oulu, Finland, see Kuusisto and Mattila 1990), RAMSIS (Human Solutions, Germany 2010), SAFEWORK (initially Safework Inc., Canada, now part of Dassault Systemes, France, see Fortin et al. 1990; Dassault Systemes 2010), SAMMIE (SAMMIE CAD Ltd., UK, 2010), SANTOS (Santos Human Inc., USA 2010), TADAPS (University of Twente, The Netherlands, see Westerink et al. 1990), and WERNER (Institute of Occupational Health, University of Dortmund, Germany, see Kloke 1990).

The differences between the systems can be examined at a number of levels (adapted from Porter, Case, and Freer 1999; Wegner et al. 2007):

- The complexity of the human model (2D or 3D, number of skeletal links, realism of flesh form, use of body scanned data, realistic and poseable extremities [hands/feet])
- The underlying data that the human model is driven by and the data available to the user (anthropometric databases)
- The extent of control over the size of the human model as a whole and for individual body segments (fixed, linear scaling, data driven)
- The extent of control over the shape of the human model to represent relative levels of fatness, thinness, or muscularity
- The implementation of joint mobility and associated constraints that limit motion of the human model to realistic postures
- Integration and or data sharing with CAD modeling facilities
- The ability to provide functional modeling of the environment (hierarchical control of model elements, manipulation of interactive elements, reflections, shadows, etc.)
- The assessment of the human model's reach, fit, or vision (manual or automated reach to point, volumetric reach envelopes, collision or intersection detection, human's view and mirror views)
- The ability to factor in allowances for shoes, gloves, helmets, and other clothing or personal protective wear (PPE)
- Biomechanical analyses and tools (strength data, torque loads on selected joints, etc.)
- The integration of dynamic assessments and behavioral data (training simulation, task analysis, scenario testing)
- Other useful assessment tools and features such as collision detection

Hardware system support is now almost universally PC based and modern multi-core PCs with modest graphics cards are typically more than capable of running most DHM systems. However, systems do vary in cost. Evaluating cost is not straightforward with a number of systems becoming a "module" within a complete CAD system. Thus, the user will require the CAD system before being able to purchase and use the human modeler.

20.1.2 Use of Digital Human Modeling in Design

It has long been argued that there should be ergonomics input at the very early stages of any design process. Basic ergonomics criteria, such as the adoption of healthy and efficient postures for the full range of potential users, need to be addressed at an early stage when modifications to the design can be implemented quickly and with minimum cost. However, this situation is far from common. Many design projects wait until the design is more mature before involving any significant ergonomics input. Traditionally, design elements such as styling and engineering have taken precedence, particularly in the automotive world. Consequently, ergonomics input has to be made in light of significant constraints and any ability to change the design is severely limited (Porter and Porter 2001). Part of the reason for this lack of timely ergonomics input can be summarized by eight fundamental fallacies (Pheasant 1996; Porter and Porter 1997):

- *The design is satisfactory for me—it will, therefore, be satisfactory for everybody else*
  A common misconception that if one person is satisfied, we all will be.
- *This design is satisfactory for the average person—it will, therefore, be satisfactory for everybody else*

Unfortunately, the average person does not exist. Part of the responsibility for this fallacy is down to terminology. The mean is often used to represent "most" when in reality it just indicates that half are larger and half are smaller.

- *The variability of human beings is so great that it cannot possibly be catered for in any design—but since people are wonderfully adaptable it doesn't matter anyway*

    People are adaptable but not enough to make up for poor design.
- *Ergonomics is expensive and since products are actually purchased on appearance and styling, ergonomics considerations may conveniently be ignored*

    Ergonomics can be expensive if it is an afterthought. Fundamentally, making something the right size and shape need not be more expensive than making it the wrong size and shape. Another take on this might be that spending a little on good ergonomics input up front is much cheaper than dealing with expensive warranty or legal problems once the product is in the market place, due to lack of ergonomics consideration.
- *Ergonomics is an excellent idea. I always design things with ergonomics in mind, but I do it intuitively and rely on common sense so I don't need tables of data*

    The reliance on intuition is unlikely to be successful because of the variety of users to accommodate. It is much more successful to design from a point of knowledge with as full a set of data about end users as is possible than to design from a point of ignorance.
- *The design is not satisfactory for me—it will, therefore, be unsatisfactory for everybody else*

    An alternative to the first fallacy. The consequences of modifying a design to overcome a particular problem must be carefully considered with respect to all end users. A modification that accommodates one subset of users may well end up designing out an even larger number.
- *Percentiles are a clear and simple way to present and use information concerning body size*

    Percentiles are easy to understand but not easy to use. The typical examples of 5th and 95th percentile people are a complete myth, there is poor correlation between body dimensions and so people with the same stature will have markedly different leg lengths, arm lengths, etc.
- *Designing from 5th percentile female to 95th percentile male dimensions will accommodate 95% of people*

    This is true if only one dimension is relevant to the design solution. However, this is a rare case and most designs require multivariate accommodation (see Section 20.2.2). Once a number of variables are considered, most cases show that a different set of people will be designed out on each variable. Thus, a solution that designs out 5% of the population on stature may design out an entirely different 5% on leg length and a different 5% again on arm length and so on.

The use of DHM systems is effectively a means of performing user trials in a virtual environment. User trials employ a panel of users carefully selected to be representative of the population at which the design has been targeted. The panel is then used to evaluate the design against a set of criteria in order to determine a level of suitability of the design. Performing this task in the virtual environment is not ideal. As has already been discussed, the richness of data that can be elicited from a real user trial can never be replicated through DHM. However, design is increasingly CAD driven. CAD models are often available at a very early stage in the design process and DHM is one means of exploiting these data. Scenarios can be explored, issues of fit, reach, and vision can be evaluated, and design limits can be established all before any physical prototypes are built. Performing appropriate ergonomics evaluations in this way, early in the design process, can establish a fundamentally sound ergonomic solution, thereby avoiding, or certainly limiting, ergonomics problems as the design matures.

20.2 UNDERSTANDING THE END USER

In exactly the same way as good design requires a thorough understanding of those being designed for, DHM requires that the user of the DHM system is aware of the intended end users, their characteristics (size, shape, capability, etc.), the tasks they are likely to perform, and the environment in which those tasks will be performed. It is true that DHM systems can be used equally well to support bad decisions as well as good ones and a thorough understanding of the end user can help avoid these mistakes.

20.2.1 Available Data

An often overlooked starting point for a design is to have a clear acknowledgement of who the intended users will be. If DHM is to be used effectively to investigate how well human variability, in terms of size and shape, is accommodated by the design, the client must make important decisions about an acceptable accommodation range and the user population in terms of nationality, sex, age, and ability, at the earliest stage of design.

The data used to support DHM are essentially related to human size and shape. In addition, data may also be used to drive joint mobility and other developments, such as dynamic movement and behavior. While most DHMs have data embedded within them, it is important for the designer to be aware of the characteristics of that particular source and the impact this may have on their design decision making and to what extent they follow any findings provided by using a DHM within their design process. The designer must also be aware of the need to potentially use multiple sources of data to achieve the scope of representation they are looking for and to address the variations of people within a population. However, even in so-called population databases there are limitations placed on the scope of the data.

20.2.1.1 Anthropometry

Anthropometric data are the key data source for DHM and without it all DHMs would be a purely notional representation of the human form that would essentially look like a human but with no actual basis in reality. Typically, anthropometric data concern the dimensions of the human body taken from reliable and repeatable external measures of the human body. These measures then typically concern: the length of limbs or combinations of limbs in various poses, e.g., stature, sitting height, buttock-knee length, arm length, foot length, etc.; and breadths or girths, e.g., shoulder breadth, waist circumference, sitting thick depth, etc. The specifications for these measures are available in various literature and, in particular, standards such as BS EN ISO 7250-1 (2008).

The way in which these data are used within a DHM system varies, mainly based on the format of its representation. The primary method of controlling the human model's size is by selecting a "percentile" that can be applied to the whole body or to individual limbs. Percentiles are the most common way in which anthropometric data are presented. Each set of anthropometric data consist of a set of mean values and standard deviations for each dimension. This information is sufficient to describe a "normal" frequency distribution in which the variability of a dimension is evenly distributed about the mean.

The nature of the normal distribution is that there are more members of a population closer to the mean, for a given dimension, and less toward the two size extremes (i.e., very large or very small). Figure 20.3 shows the frequency distribution for the stature of British men, and is an example of a normal distribution. The symmetry of the curve shows that 50% of the population is shorter than the average, and 50% are taller. The mean can therefore be referred to as the 50th percentile. In general, it can be seen that *n*% of people are shorter than the *n*th percentile.

Using the mean and standard deviation of a distribution and the relevant equations, the more flexible DHM systems can then generate any percentile size value from the data, from 1st to 99th (see Figure 20.4). To simplify the process of creating a human model, most systems can create the

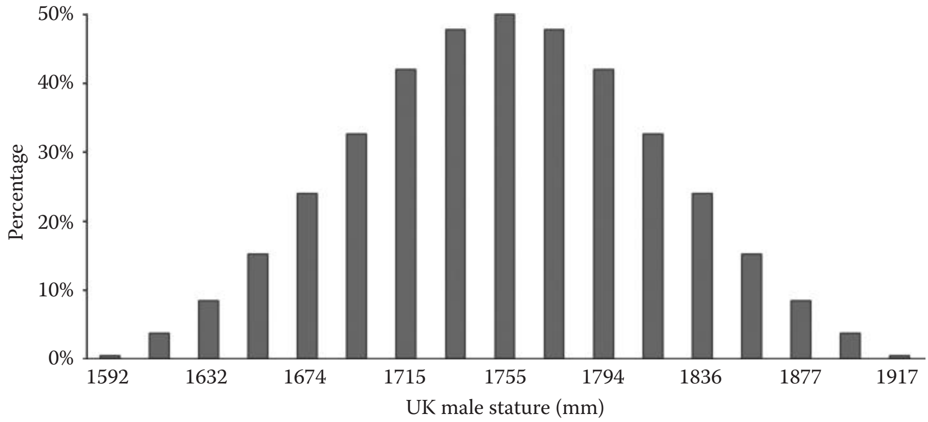


FIGURE 20.3 Stature of UK males showing a typical normal distribution. (Data from ADULTDATA, *The Handbook of Adult Anthropometry and Strength Measurements – Data for Design Safety*, Department of Trade and Industry, London, 1998.)

complete human from just a stature percentile. When this is done, all the various limb dimensions for the human model are also given the same percentile wherever possible (however, this is not a straightforward process as discussed below). It is from this that the commonly used limits of 5th to 95th percentile are used to represent a population for ergonomics analyses. Again, the more flexible DHM systems also allow individual body dimensions to be varied by percentile. Thus, a human model can be constructed to have a range of percentile values for various parts of the body.

One particular issue for the direct application of anthropometry within DHM is the application of external vs. internal anthropometry. External anthropometry is the type described earlier, where landmarks of the body are directly measured and is the most commonly available type. However, external anthropometry poses difficulties for use within DHM. The main problem with external anthropometry is determining the size and location of the relevant link or bone within the external dimension. For example, consider the buttock-knee length measurement. For a given measurement, there is no accurate way of knowing the dimension of the thigh link. Ideally, DHM systems would

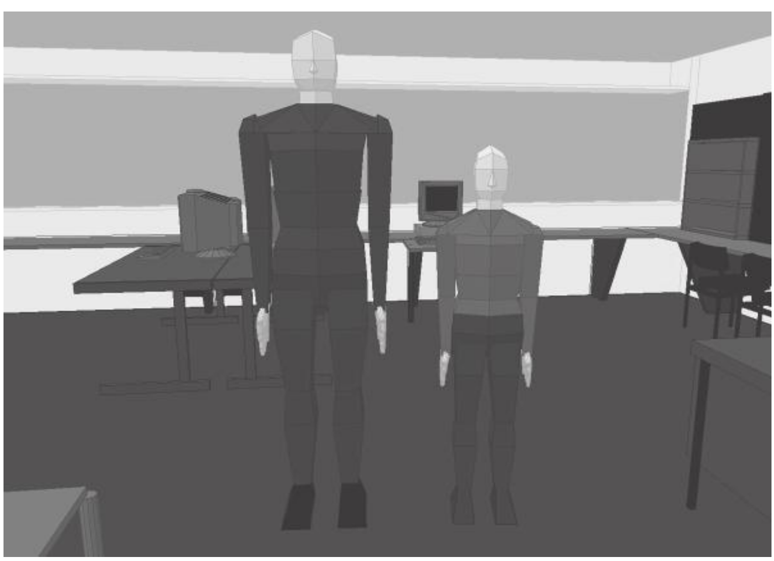


FIGURE 20.4 1st percentile female and 99th percentile male UK DHMs in SAMMIE.

employ internal anthropometry, essentially the direct measure of the links within the human body, but these are extremely difficult to obtain either from the literature or to measure directly. To overcome such problems, equations are used to approximate the link lengths as, ultimately, the human model must have a consistent set of both internal and external measures when both seated and standing, i.e., the stature dimension must equal the sum of the foot (floor to ankle), calf, thigh, spine, neck, and head links when stood (see Figure 20.5). In most cases, the user is shielded from these issues by the design of the DHM system and yet, essentially, the system is building a number of assumptions into the human model. These assumptions may then affect the accuracy of an evaluation, particularly for human models that exhibit a greater degree of fatness (or ectomorphy, Sheldon 1954), where the discrepancy between the external and internal anthropometry will be greater.

Traditionally, anthropometry has been collected using simple mechanical instruments, such as the tape measure, the goniometer, the anthropometer, the stadiometer, and the sitting height table, to measure various dimensions of the body. However, a significant development in anthropometry has been the use of 3D body scanning techniques. Body scanners typically consist of some form of booth in which the human form is scanned, either by a laser or by projection of a light pattern. This scan results in a series of points that lie on the surface of the scanned body (see Figure 20.6). Software is then used to link these points to form a mesh that represents the surface form of the human. These systems are very accurate (typically around 1 mm), particularly compared to traditional techniques and with further software manipulation the dimensions of both external measures and internal link dimensions can be extracted (TC^2 2010; Vitronic 2010).

Body scanning has a number of useful features. The ability to obtain external and internal anthropometry removes the issue described earlier inherent in manual techniques, though it should be noted that the joint locations are themselves calculated as opposed to being directly measured by the body scanner and thus, in reality, one set of assumptions are being replaced by another. Potentially, the most interesting feature of body-scanned data is the quality of the representation

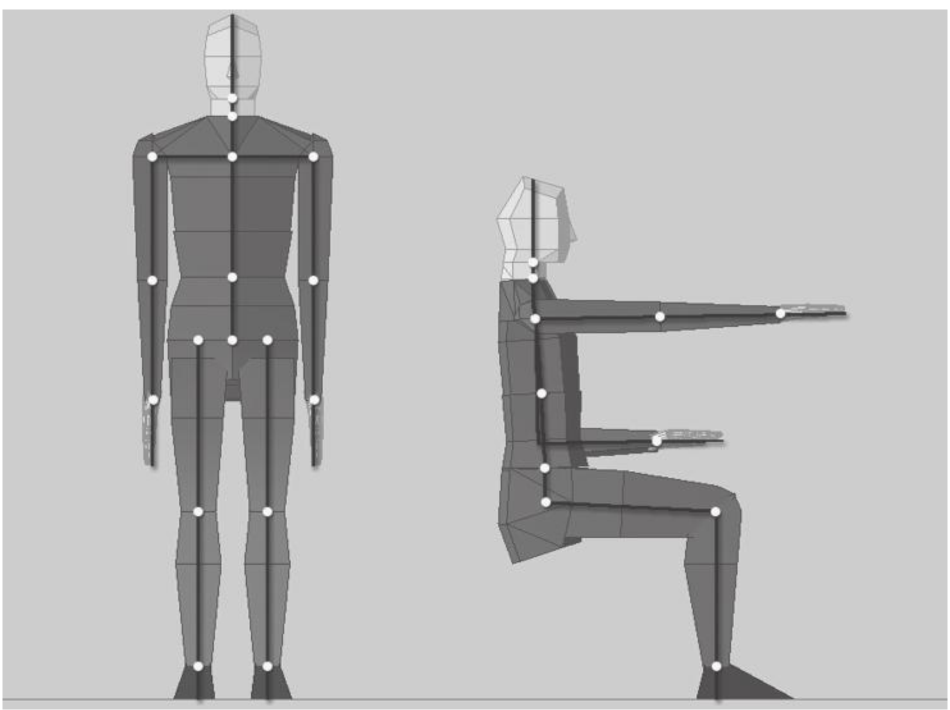


FIGURE 20.5 DHMs within the SAMMIE system showing the internal link structure and the need for percentile consistency between poses.

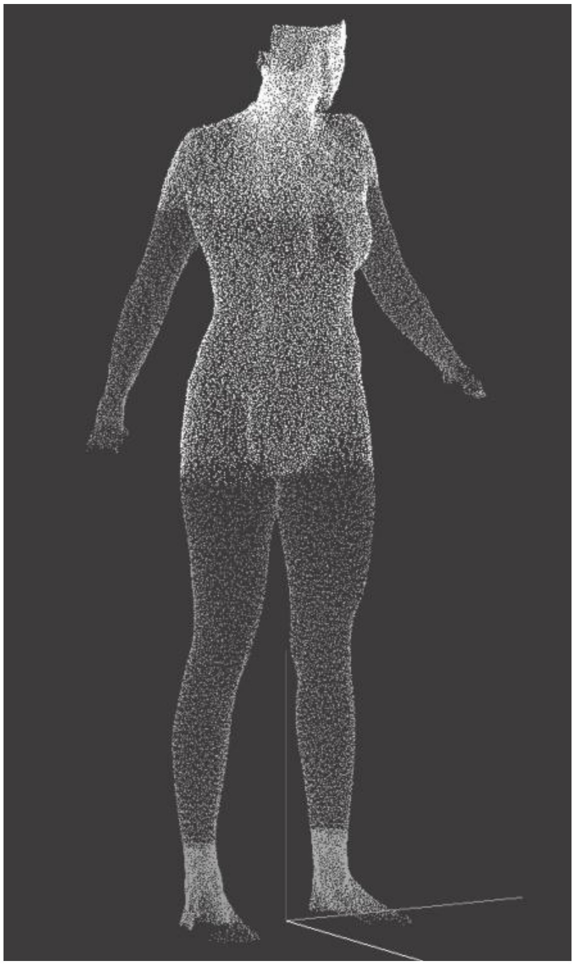


FIGURE 20.6 A 3D body scan captured from a TC^2 NX12 full body scanner.

of the external human form, or essentially the shape of the body. Until recently, DHMs have been rough approximations of the human form. This approximation was due to a number of factors consisting of the technology's ability to handle the form complexity, the ability to actually measure the form, and a user-friendly way of being able to manipulate the form for different human models. This led to the widespread use of the segmented or "action man"-style human models seen in the majority of systems. Body scanning now allows accurate flesh representations to be achieved and the computer technology is more than capable of dealing with the amount of data. This level of accuracy and detail provides the potential to assess the interface between the human model and its environment to a much greater depth, such as deformation of a seat cushion when someone sits on it, or the impact of using a seat belt across the abdomen of a pregnant female. This improved accuracy and realism does, however, raise a further set of issues. In particular, the realistic flesh form obtained from a 3D scan is a static snapshot taken in a particular posture. Thus, the ability to dynamically deform the flesh becomes a concern, in particular, flesh deformation at the joints and the ability of the flesh to deform in response to external forces (i.e., the seat and the buttocks/thighs deform when someone sits in a chair). Some current DHM systems do offer flesh deformation at the joints, however it is typically a visual representation with no anthropometric data to support it. More accurate models of these issues are in development, but are, at present, largely areas for research (Dong et al. 2002; Vassilev and Spanlang 2002).

While anthropometric data are relatively easily obtained, users should be aware of a number of issues. One of the most common anthropometric databases in the UK is ADULTDATA, published by the Department of Trade and Industry (1998). ADULTDATA is actually a compendium of data from other sources drawn together in one useful volume (including Pheasant [1996] and PeopleSize [1998]). The data span a large range of physical body measurements (266) obtained from multiple nationalities. However, not all measures are available for all nationalities, so for example it is possible to obtain a stature measurement for the German population, but there are no German data for arm length. In addition, most of the data are relatively old. ADULTDATA was published in 1998, but the sources of data within it range from 1969 to 1998. The data have been statistically treated through ratio scaling to factor in increases in stature and weight in many of the world's populations over this time period, however these are further assumptions that are being made, which will have an effect on the accuracy of any evaluations being made. Other issues include: the fact that the Chinese data were actually collected from Singapore and Hong Kong; some of the other sources are taken only from particular occupations such as Swedish and Polish workers, and French car drivers; and some of the sample sizes are relatively modest (1051 people) to be representative of a whole nationality.

Other databases, such as SizeUK (Treleaven 2007; SizeUK 2010) and CAESAR (Robinette, Daanen, and Paquet 1999; CAESAR 2010) have been collected using the body scanning technologies discussed earlier and provide a very large array of measurements taken from many thousands of people. The number of people, their age, and sampling strategies make them much more representative of their respective populations. However, these very large and potentially useful databases also have limitations. Typically, they have been collected for a need other than DHM. For instance, SizeUK was collected for the retail clothing industry. As such, it contains many hundreds of external surface measurements (e.g., coat sleeve, armscye, etc.) that are not relevant to DHM needs. More importantly, it does not contain some potentially critical measures such as any of those collected in a seated pose. While it is possible to reverse engineer these poses from the data, it is likely that this will introduce a degree of error and call into question the validity of the source for use in DHM. Finally, and potentially most significantly, such databases are relatively expensive and beyond the reach of many designers.

Further limitations, particularly relevant to designers wishing to design for the broadest range of people, relate to the age range of the samples in the databases. ADULTDATA and CAESAR do not have data on people who are older than 65 years, although SizeUK does have people up to the age of 91, and Older ADULTDATA (one of the ADULTDATA series together with Childdata) has data from people over 90 for some nationalities. This is a common limitation and so most anthropometric databases do not factor in changes to body size and shape as people age. Also, the lack of data from people with impairments is a fundamental issue. The effects of common impairments are rarely reflected in anthropometric data and when they are they tend to be from samples of limited size or with other limiting factors (Paquet and Feathers 2004; Das and Kozey 1999; Hobson and Molenbroek 1990; Goswami, Ganguli, and Chatterjee 1987).

While all of the limitations above are often explicitly stated in the databases, what is not clear is the impact these limitations have if the data are used for DHM purposes. Issues associated with the age of the data may be relatively minor, issues to do with the age of the people in the data are more significant, issues arising from only having data on able-bodied people when wishing to design to include all people, including those with disabilities, are fundamental.

From a DHM perspective, it is important to have access to a range of anthropometric data in order to represent both a range of sizes and shapes within a population and also a range of populations. Thus, data for males and females of different age ranges and different nationalities would be a minimum requirement for most design applications. However, some applications may require specialized data that refer to specific sub-sets of the population, such as military data that would once have been almost entirely male and even now would still have characteristics that make data from the population as a whole unsuitable for military ergonomics evaluations. Thus, it is critically important that any DHM user is aware of these issues and has a means to obtain the data necessary for their design task or, at the very least, a way to manage any limitations to the data available or assumptions that will have to be made.

20.2.1.2 Joint Mobility

In addition to accurately representing the size and shape of the human form, DHM systems provide a means to articulate the DHM to allow the virtual human to adopt different postures. Most human models consist of a set of jointed "links" that represent the human skeleton, together with a solid or surface envelope that represents the flesh. Early developments consisted of a limited number of links to simplify the human skeleton, with a similar number of flesh "segments" attached to the links. The work of Dreyfus (1964) had a considerable influence on DHM, providing a simplified link structure for a human model together with dimensions and ranges of motion for these links. Since this early work, some DHM systems have gone on to develop more realistic skeletal structures, particularly for the spine.

Joint mobility is a complex area, particularly for joints such as the shoulder and thigh. This complexity is manifest in the development of DHM systems, but more explicitly in the way in which a DHM system user can pose or directly manipulate the limbs of the human model. Typically, the human model will be manipulated through the selection and movement of a limb or body segment with any associated limb segments moving with it. The exact means by which this happens will vary based on the system used, but essentially fall into two main methods: a forward kinematic model where, for example, the upper arm may be rotated, and the lower arm and hand rotate with it; and an inverse kinematic model where, for example, the hand is dragged across a surface and the lower arm, upper arm, shoulder, and possibly spine etc. are dragged with it. Both methods present their own advantages and disadvantages.

To ensure joint mobility is realistic, some DHM systems provide joint constraints. These constraints limit joint movement to ranges actually achievable by humans. This ensures that unrealistic postures cannot be adopted. However, this is another area of difficulty for DHM as data are particularly difficult to obtain. As with anthropometry, joint mobility data have a number of concerns that limit its effectiveness within the DHM system. While these complexities are largely beyond the scope of this chapter, it is not difficult to imagine the ethical issues of trying to obtain absolute joint limits from the population.

The presence of joint constraints not only ensures realistic postures can be adopted, but also provides a basis for reach assessment functionality. DHMs typically provide two different reach assessment methodologies: direct reach and volumetric reach "envelopes." Direct reach allows the DHM system user to select a reach "target" (button to be pushed or lever to be gripped), and then to get the DHM to attempt to reach that target within certain constraints (e.g., the torso remains fixed and only the arm can be moved). If the DHM can be postured to achieve a solution the DHM will be made to reach, if not, typically an "out of reach" distance will be supplied to give an indication of the degree of failure. Volumetric reach envelopes provide a graphical representation of the total volume that is reachable by a selected arm (see Figure 20.7). The presence of the reach target within the volume suggests that it is reachable. Volumetric reach is a very useful and quick analysis tool, but care must be taken in relying on it as the only source of reach assessment. While the volume is representative of what is possible, it does not take into account the influence of the environment, such as the influence of seat surfaces, safety barriers, or other elements that may restrict movement of the DHM.

Another factor influenced by joint mobility and a direct influence on reach assessment is that of extremities: hands and feet. A number of DHM systems have simplified hand and feet models. The reasons for this relate again to the lack of data to drive the generation of these limbs and also the difficulty in providing a suitable interface for the user to make manipulating hands and feet acceptable. Posing a hand through manipulation of individual links has the equivalent complexity to posing the rest of the body. Those systems with representative extremity models (normally limited to hands) tend to drive hand postures through the concept of grip types (see Figure 20.8). Thus,

FIGURE 20.7 A DHM with a reach envelope for the right arm in SAMMIE.

interaction by the user is simplified by specifying a predetermined grip type, e.g., pointing with the index finger, thumb tip grip, fist grip, etc., or by the system wrapping the fingers around a selected target to establish a grip. Both systems are driven by joint mobility of the hand links. Representative hand and feet models are particularly important for reach task assessment as each task will require a different grip type depending on the action required for the control interaction, thereby effectively modifying the length of the reaching limb. Inappropriate use of grip, or failure to factor this in, will essentially lead to an inaccurate reach-ability assessment or incorrect design or location of controls or other interaction points.

20.2.2 Multivariate Accommodation

Assuming data to be available, another significant issue is how DHM system users might apply the data to common design problems. The presentation of anthropometric data, and thus most DHMs, as percentiles seems straightforward but is notoriously confusing and has a number of issues when it is used for design (Porter et al. 2004).

The issue of multivariate accommodation is rarely addressed. Most design problems are multivariate and yet percentiles are univariate. Most anthropometric databases only provide data on 5th, 50th, and 95th percentile measurements. In addition, designing to accommodate from a 5th

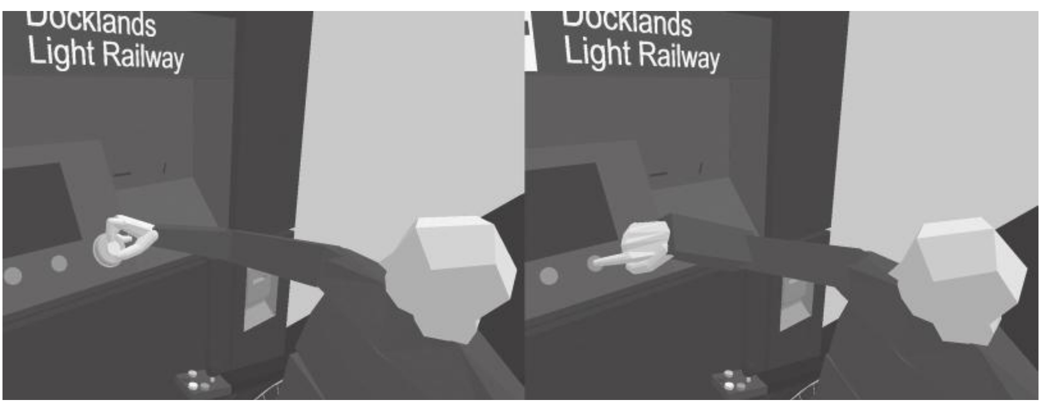


FIGURE 20.8 Various hand grip types within SAMMIE.

percentile female to a 95th percentile male has become a standard in many fields (BS EN ISO 15537 2004). This encourages designers and indeed even supports designers in excluding 5% of the population. Even though other percentiles can often be calculated, this is far from explicit and not clear for a non-expert user.

A further issue is the lack of correlation between body dimensions. A 5th percentile female (based on stature) is unlikely to have 5th percentile values for other measures, such as knee height, sitting height, thigh breadth, etc. As such, when designing from 5th percentile female to 95th percentile male, a different 5% will be designed out for every dimension considered. For example, Herman Miller, provider of office furniture and services, performed a chair design using 5th to 95th percentile values. They found that when using only four variables: popliteal height (seat height), buttock to popliteal length (seat depth), elbow height, and lumbar height, the design only accommodated 68% of the population even though the starting intention was to design for 95% (Stumpf, Chadwick, and Dowell 2001).

The process of breaking down people into individual measures (arm length, sitting height, etc.) into tables of data removes the link between these variables as exhibited by any one individual. This means that it is not possible to use the data sets to understand the variability in body size (such as the ratio of leg length to body length) illustrated above. This has particular impact when designing products that have a number of variables that require adjustment (multivariate), such as an office chair or a car seating position. A car seat is generally adjustable forward and backward to allow correct reach to the pedals, and also allows adjustability of the seat height and back rest angle. The user must be able to reach the steering wheel, which may also have some form of fore/aft adjustability. When using anthropometric data to design the adjustability ranges that are built into the seat and steering wheel, it is useful to understand the prevalence of people that would be considered "worst case scenarios" for such design activity. An example of this would be a tall driver, with long legs and long body, but relatively short arms. The long legs take the user further away from the steering wheel and the roof line forces the user to recline the seat more than usual to allow sufficient head clearance, again taking the user further from the steering wheel. The relatively short arms of the "worst case scenario" would then generally find it difficult to reach the steering wheel, forcing a slumped posture that is likely to cause lower back problems.

If the DHM system user is not easily able to model these "worst case scenarios," then multivariate accommodation becomes extremely difficult to do with any degree of confidence. Assessments can be performed but their representativeness of the population is limited. These issues are compounded when the design in question has to meet the needs of the whole population, including those who are older or who have disabilities. Compromises in the accommodation of the design can often be overcome by people as humans are generally able to adapt, often by adopting a compromised posture. However, those who are older or who have some form of impairment may be unable to adapt in this manner and thus become more than merely disadvantaged, they are likely to be excluded. It is only by collecting new datasets that maintain the links between the anthropometric data for any one person, that these issues can be better understood.

A recent development that addresses one of the concerns with multivariate accommodation is the A-CADRE family of DHMs (Bittner 2000). A-CADRE is a statistically derived family of 17 DHMs that have been designed to represent both the breadth of the population but also more accurately represent the extremes of the population. In particular, they represent "interesting" body proportionality, such as people with relatively long legs and tall bodies and short arms, or short legs and tall bodies and long arms. While the use of A-CADRE does not cover 100% of the population, used in combination with other techniques, it can remove some of the uncertainty from the process and simplify the use of DHM for the less experienced user.

A further development is that of HADRIAN (Human Anthropometric Data Requirements Investigation and Analysis; Marshall et al. 2004, 2009), which works together with the SAMMIE DHM system. HADRIAN is a combined database and task analysis tool. The data cover a broad range of measures applicable to DHM captured from 102 people, many of whom are older or who

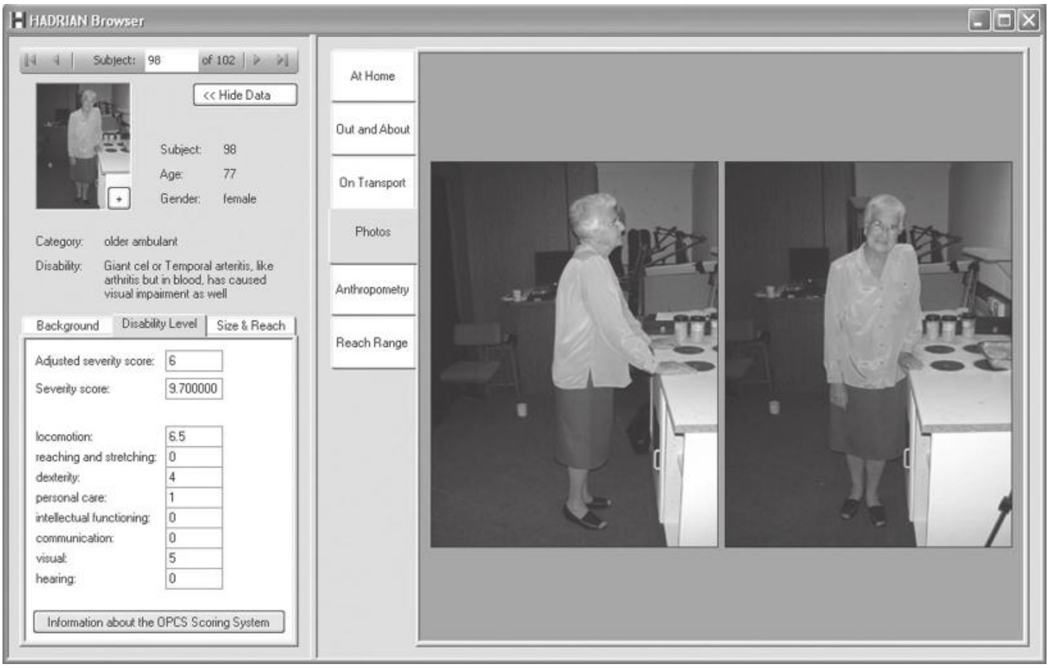


FIGURE 20.9 The HADRIAN database, showing one individual.

have disabilities. In contrast to other anthropometric sources, the data within HADRIAN are maintained as an individual (see Figure 20.9). As such, the complexities of having to recreate people from statistical tables of limb lengths are removed, and the validity of the human models created from the data is assured. In addition to the data, HADRIAN provides an alternative means of employing the people in the database for ergonomics assessments within a DHM system. Through the use of a task analysis interface, HADRIAN automates the creation of the people in the database with representative size, shape, joint mobility, and behavior, and manipulates the virtual humans within a DHM environment in an attempt to perform the task as defined. The user is then presented with a view of the individuals in the database who failed the task and why. This novel approach to the use of DHM addresses some of the key issues highlighted in this chapter. Applicable data are provided with the tool, issues to do with understanding the data or having to factor in limitations of the data are largely eliminated. In addition, the complexities of creating and employing the most appropriate human models for an assessment are eliminated by the ability to rapidly assess over 100 people. However, HADRIAN is the focus of ongoing research and is not currently available for commercial use.

20.2.3 Tasks and the Environment

In order to use a DHM within the design process, it is important to establish a clear definition of all the tasks the users will be required to perform when using the intended design. The use of DHM systems can often highlight conflicts between tasks or even the ability to accommodate additional tasks. While a thorough treatment of task analysis is beyond the remit of this chapter, it is sufficient for the DHM user to recognize the need to identify the relevant tasks, to decompose these tasks into suitable elements, and ultimately translate these into assessments to be performed within the DHM system. The majority of DHM systems are not currently capable of being driven by task definition alone. As such, the DHM cannot be told to "move a packing crate" or to "drive a car." Instead, the DHM user must interpret "drive a car" into a series of elements such as "view instruments," "view road ahead," "view mirrors," "reach steering wheel," "reach gear lever," "reach accelerator pedal," etc., that may be assessed to establish the feasibility of the task. While this serves to outline the general need for task analysis within DHM, there are a number of levels of detail and understanding beyond this simplistic treatment. For example, the task element "reach to gear stick" still needs interpretation to understand that the gear stick is unlikely to be a fixed reach point. The DHM system user will need to again establish what is likely to be the worst case scenarios (i.e., furthest gear location away from the driver [5th gear]) and evaluate those or else assess every possible location of the gear stick.

A further complexity is that the data used to drive the human model are largely unspecific to a particular task or environment. Yet, the design they are being applied to is likely to be very specific. One simple illustration of this is that data are often collected without clothing, yet there are few design situations where we would need to know the dimensions of the naked population. Factoring in standard clothing allowances makes the task much more complex and requires a high level of experience and expertise; to allow for heavy, bulky, and restrictive safety equipment is more complex again. In an inclusive design context, the task and environment may be relatively common, cooking a meal in a kitchen or getting a ticket from a ticket machine on a train platform. However, older and disabled people often employ coping strategies that mitigate against any impairment they may have. These coping strategies are rarely documented and add yet another layer of complexity for the DHM user.

The definition of tasks to be performed by the end user should also be conducted in full knowledge of the environment in which the tasks will be conducted and any possible effects on the performance of those tasks. Clearly, the interaction of a DHM and its environment is an integral part of any analysis. Some DHM systems provide tools to help with these issues, such as measurement capabilities to assess clearances or collision detection to prevent the DHM from reaching through an object. However, most interactions are very subtle. As discussed, DHMs do not have flesh that is deformable due to external forces. Thus, other tools or experience must be used to determine the effects of the environment on the DHM. One typical example that will be illustrated in the case study in Section 20.4 is that of seat compression. There is very little information on how to position a DHM with respect to a seat surface. Even this simple sounding example has multiple variables such as the compression of the skin and the seat surface, which are affected by the properties of the human (weight etc.) and the material the seat is constructed from.

In all cases, irrespective of complexity, it is critical that the DHM system user is aware of the relevant issues for the assessment being performed. In many cases, assumptions will have to be made in the absence of applicable data. This is an accepted part of DHM, but it is important that these issues are dealt with in a rigorous and transparent manner and that their impact on any recommendation made from an assessment is fully understood.

20.3 USE OF DIGITAL HUMAN MODELS

Having identified the potential users, the tasks they will perform and under what circumstances, DHM can then be used proactively during the design process. To encourage their use within the early stages of design, DHM systems can often be used effectively with only the simplest of design models. Areas of common reach and vision for various sized human models can be identified to guide the placement of controls and displays before these items have been actually designed in detail. The minimum volume of space required by the human models to adopt their various task postures is easily observed at the earliest stages of design and this provides the possibility of ensuring that sufficient clearances are provided as the design progresses. This simultaneous consideration of people issues and product issues promotes the identification of optimum compromises that are essential for a successful design.

The use of ergonomics and DHM in a proactive manner can also heavily reduce project time scales. As many projects now move to a digital CAD environment at a very early stage, DHMs can be used increasingly early to establish critical design parameters. Issues regarding fit, working postures, the layout of controls and displays, visibility, access, etc., can all be established using a relatively basic CAD model and basic engineering data and user requirements. This, in turn, can be refined iteratively as the design becomes more mature. As all of the requirements, including human factors issues, are being considered and validated during this process, the design is much more likely to be “right first time.” This approach then reduces the need for downstream prototypes, user testing, and the subsequent design changes that are likely to result.

From a financial perspective, the use of DHM can produce significant cost reductions. As highlighted earlier in this chapter, DHM systems can be very expensive yet their cost can be very reasonable when compared to the equivalent cost of full-size mock-ups. In addition, reductions in development time, in modifications due to problems highlighted by user trials, and in warranty and product returns will all help to reduce costs.

The use of DHM can also act as a catalyst for communication and collaboration within a design project. Ergonomics problems with a proposed design can be presented in a highly visual manner that is both accurate and yet accessible to non-experts. The use of DHM systems is also systematic and objective in its approach, which enables all stake holders in a project (such as the designers, manufacturers, installers, operators, maintainers, and recyclers) to examine any assumptions and constraints and to question the conclusions drawn. DHM systems are used as both a tool for ergonomics analyses and as a medium for communication. Work is conducted “on screen” and requires a high degree of interaction between the members of the design team. Working computer models are often very simple as this helps to focus on the important ergonomics issues. However, when concepts are to be presented to the client, a significant amount of effort is put into creating a visually accurate model as this helps to impart a greater sense of validity. It is much more persuasive to embody a good ergonomics specification into a CAD model than it is to present a written report listing ergonomics recommendations. However, care must still be taken to avoid the pitfalls of the appealing and accessible nature of computer-based visualizations. The presentation of visually appealing solutions in the digital environment can still mask the important ergonomics issues if care is not taken.

20.3.1 Assessment Tools and Future Developments

As we have seen, the basic structure and make-up of the DHM is inherently suited to assessing fit, posture, and reach within the virtual environment. In addition, DHM systems are often used for visual assessments. Visual assessments are often split into direct visual assessments and volumetric vision “cones” in a similar manner to reach. Direct visual assessments use a combination of the joint limitations of the DHM together with an understanding of the visual field of humans to provide a “human’s view” on screen (see Figure 20.10). Objects that fall within this field of view are assumed to be directly visible. Volumetric vision “cones” are the visual equivalent of reach envelopes (see Figure 20.11). A volume is projected from the eye point of the DHM that represents the viewable volume of the DHM. The benefit of view cones is the ability to show different levels of visual acuity with layers of cones representing the optimum areas for reading tasks through to those areas within peripheral vision.

In addition to these basic assessment tools, DHM systems have developed over the years to provide new user interface approaches to make these more intuitive and easier for the user to acquire the information they need for a design. However, they have also developed a broad range of other features to assist in virtual ergonomics assessments. Some of the developments are advancements of basic reach, vision, and posture tools: the projection of fields of view through apertures such as car windows (e.g., the P-NCAP projection facility with SAMMIE; see Figure 20.12) and reflections in mirrors; reach enhancements like automatic reach and grip methods that reduce the need to directly drive the human model’s limbs; and posturing methods that can place a human in a specified posture (e.g., driving) based on the need to interact with a number of other elements, seat, steering wheel, pedals, etc.

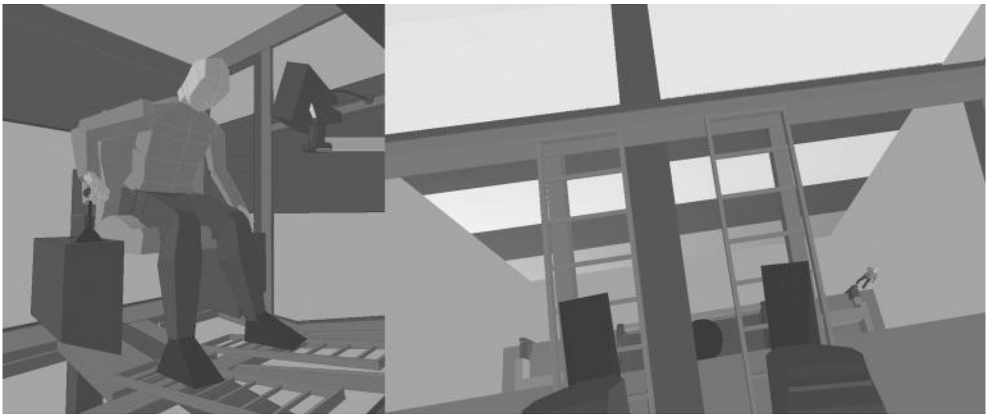


FIGURE 20.10 A crane operator modeled in SAMMIE showing direct vision from the DHM's eye point shown on the right of the image.

Increasingly, DHM systems offer a range of biomechanical analyses, including spinal loading and standard assessments such as the NIOSH lifting equation (NIOSH 2010), RULA (2010) and OWAS (2010). However, the most recent and possibly most important trend is the move toward dynamic assessment and the inclusion of the task-based approach to computer-based ergonomics evaluations. Typically, DHM systems support static analyses of a single posture. If a task was to be assessed then a series of static postures would be assessed, normally at the extremes of motion. The actual behavior of the human model would be driven from the experience of the system user, normally from observations of real people performing the task being evaluated. Now systems are being developed that dynamically evaluate the human model's interaction with its environment. In addition, rather than relying entirely on the expertise of the user, behavior modeling is being included into these systems so that the human models will attempt to replicate the behavior of real people when interacting with their environment. Examples of these developments include crash test simulations for vehicles with systems such as MADYMO (TASS 2010), PAM-CRASH, and PAM-SAFE (ESI Group 2010), training and workforce simulations with systems such as JACK and RAMSIS, and wider application such as simulating the behavior of soldiers and civilians in various real world scenarios with systems such as DI-Guy (2010) and HADRIAN (Marshall et al. 2004).

It is likely that developments in the automation of analyses, increasing levels of sophistication in dynamic and behavioral simulation, and the reduction in the need for expertise of the user to "drive"

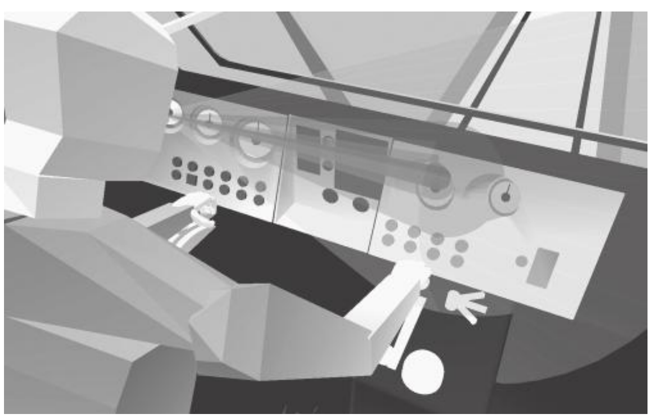


FIGURE 20.11 A vision cone projects from the DHM's eye point representing decreasing levels of resolution.

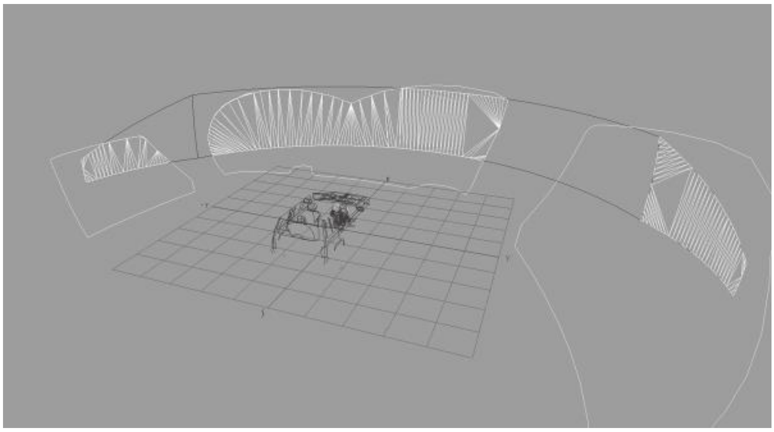


FIGURE 20.12 The P-NCAP visual assessment protocol used to project the visual field from a car windscreen in SAMMIE. The image shows the projected boundary, a rectangular clipping zone, and the tessellated common area.

the system will continue. This will lead to even greater benefits through the use of DHM systems in the design process. However, these developments will also bring their own challenges and it must be ensured that sound ergonomics principles are at the heart of any future work.

20.4 DIGITAL HUMAN MODELING CASE STUDY: THE ANALYSIS OF A CAR INTERIOR TO DETERMINE THE EXTENT OF INTERNATIONAL OCCUPANT ACCOMMODATION

The following case study provides an example of how DHM systems can be used in the design and assessment of a workstation. The case study uses the example of the design of a car interior, to provide sufficient adjustability to allow a comfortable driving posture for an international population.

20.4.1 Car Design Process

The approach for the design for occupant accommodation in vehicles is defined by a number of the Society of Automotive Engineers (SAE) standards. The standards provide guidance for the definition of seat adjustability, steering wheel adjustability, head clearance, and reach to control panels, among others. The contents of the various standards provide template data that can be used in the CAD and DHM systems that are used to design vehicles.

The key tool defined by the SAE standards is the H-Point Manikin II (SAE 2010). The SAE H-point manikin (see Figure 20.13) is a mechanical device that can be used to simulate the size of driver's buttock-knee length and knee height for a range of the population of the United States (10th percentile female to 95th percentile male). The complex dimensional referencing system used in the SAE standards relies on the hip locations, or H-points, which are derived from the use of the SAE manikin. The H-point manikin and the design process that it supports are used by the majority of automotive manufacturers, and yet the data that was used to define the adjustability ranges, and therefore the driver size variability that it can represent, are not well defined. For example, the source of the 95th percentile value for the adjustability of the lower leg of the H-point manikin is described as follows:

> Values for the 95th percentile leg lengths were developed on the basis of best judgement of available data by the Design Devices Subcommittee of the SAE Human Factors Engineering committee at the July 1968 and March 1969 meetings. (SAE 1995)

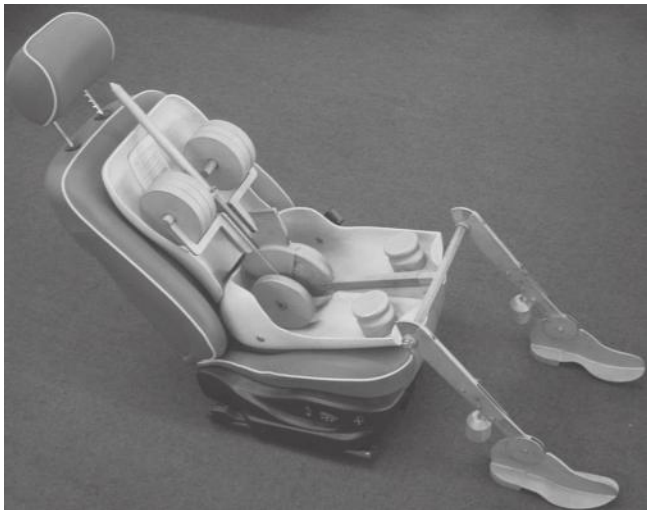


FIGURE 20.13 The SAE H-point manikin.

The quoted dimension for the 95th percentile lower leg length is 459.1 mm. This is 24.9 mm longer than the 95th percentile lower leg dimension found in the anthropometric data source ADULTDATA (1998) for the U.S. population. Other issues exist with the H-point manikin. For example, the straight-legged posture that is adopted by the H-point manikin does not replicate the actual posture used by drivers. The leg posture of larger drivers tends to include some rotation of the upper thigh, with the heel located between the accelerator and brake pedals to allow the foot to pivot when changing between accelerator and brake use. This is most evident with manual transmission cars due to the position of the clutch.

This is illustrated in Figure 20.14, using the SAMMIE system. The figure shows two human models that have been generated to represent the 95th percentile U.S. male and the 10th percentile U.S. female, i.e., the size range that the SAE manikin is designed to represent. The source of the data used to generate these models is ADULTDATA (1998). The white human figure shown in Figure 20.14 is a standard 2D template based on the size data provided by a number of SAE standards. The ellipses in front of the face of the SAE manikin represent the range of eye positions derived from the SAE data and presented as a design tool. It is clear to see that the eye positions of the two human models are outside the zones defined by the SAE data. The more up-to-date anthropometric data and simulation of posture used in the DHM system produces very different results to those derived from the SAE data. The SAE H-point manikin was updated in 2005 (SAE J4002), but still uses the same anthropometric data and manikin posture as those shown in Figure 20.13. This issue has been identified by researchers in the area of occupant accommodation. For example, Parkinson and Reed (2006) discussed the univariate nature of the SAE templates, and the potential for DHM systems to provide more accurate simulations of people at the limits of the percentile range. The more accurate replication of the human form that is possible using DHM systems can improve occupant accommodation if used appropriately during the car design process. The following case study describes how DHM systems can be used to evaluate current car interiors, providing suggestions for improved adjustability for a larger proportion of the international population.

20.4.2 Case Study: Redesign of a Car Interior to be more Inclusive of the International Population

The case study describes a hypothetical request to the DERG to perform the assessment of a vehicle interior with the aim of improving occupant accommodation. This involves the assessment of a new

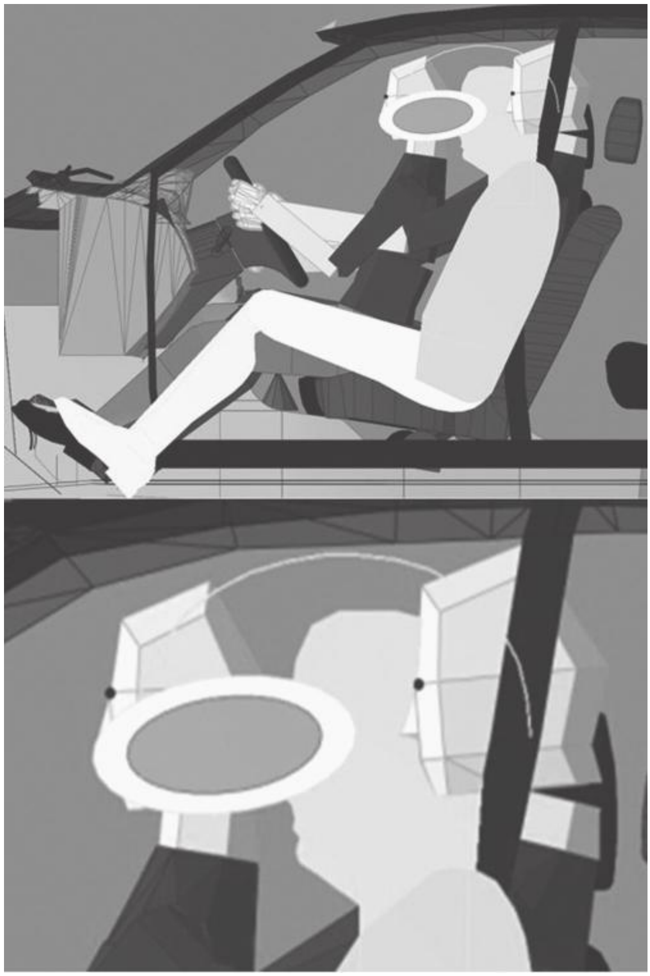


FIGURE 20.14 A comparison between the SAE eye location data and the eye points found for a 95th percentile U.S. male and a 10th percentile U.S. female.

design for a car interior that has been initially designed using the SAE H-point manikin data. For the purposes of the case study, a car interior has been modeled using data gathered from an existing small car, with the seat and steering wheel adjustability ranges accurately captured. A dash board has been designed to replicate the interior surfaces of the existing car. This CAD model has been imported into the SAMMIE DHM system for analysis. Figure 20.15 shows the car model in the SAMMIE system.

The hypothetical automotive design team has an aim of exporting vehicles to China, and has therefore requested an analysis to determine any changes to the adjustability ranges that would be required to improve accommodation for small Chinese women. To give a context for this request the SAE design process uses a minimum occupant size of a 10th percentile U.S. female, the stature of which equates to a 35th percentile Chinese female height. The implication of this is that approximately one-third of the Chinese female population would struggle to drive a car that has been designed to accommodate a 10th percentile U.S. female. The automotive design team also wishes to understand how the package of the new vehicle interior accommodates the European population, i.e., the Dutch (the tallest population on the planet). It should be noted that the following analysis shows the majority, but not all of the analysis steps that are performed during such work.

FIGURE 20.15 The car model in the SAMMIE DHM system with a small female driver interacting with the HVAC controls.

20.4.2.1 Datasets Used to Support the Analysis of a Car Interior

The DERG process used to identify the minimum and maximum accommodated driver sizes uses a number of datasets. The dataset used to define the size of human models is ADULTDATA (1998). The human models created from ADULTDATA can only ever be univariate, i.e., all body dimensions are the same percentile as the stature percentile, as discussed in Section 20.2.2. The issue of multivariate accommodation can be mitigated by using the A-CADRE human model dataset, with certain A-CADRE models being used to examine certain situations. For example, an A-CADRE human model with long legs, long body, but relatively short arms can be used to examine steering wheel adjustability ranges. The use of this A-CADRE model simulates the long legs and long upper body defining a posture that is more reclined due to the need to have clearance between the roof of the car and the head. The relatively short arms illustrate that more rearward adjustment of the steering wheel is required.

The dataset used to define the posture of the human model was produced by the DERG and disseminated in a paper by Porter and Gyi (1998). The reported study provided data on the preferred driving posture for a large range of user sizes (1st to 99.9th percentile UK). These data were gathered using a rig that allowed large adjustment ranges for the seat and steering wheel. The preferred posture data can be used to evaluate a human model posture that is derived from the constraints of the steering wheel and seat adjustability in the analysis vehicle.

The three data sources that define the human model variability are combined with data collected by the DERG for the amount that a seat will compress under a range of driver weights. It is important to understand this because of the effect that it has on the position of the driver in the car. Ideally, these data should be gathered from the seat that will be used in the production version of the car, as seats differ in terms of foam hardness and stiffness of covering material, to provide varying levels of seat compression. However, the seat selection process will generally not be performed until after the early stages of the car design process, during which DHM systems are used. If the seat has not yet been selected, compression values gathered by the DERG are used. These values have been collected from a range of car seats using a combination of the SAE H-point manikin and real users. These values have been averaged across the seats to provide standardized seat compression values for a range of driver weights. The method is therefore used with caution, with a stipulation that a physical mock-up must be produced to verify seat compression values at the appropriate stage in the design process. For females below the 33rd percentile a compression value of 30 mm is used. For males between the 33rd and 66th percentile a compression value of 50 mm is used. For males larger than the 66th percentile a value of 80 mm is used. The seat compression value is applied directly below the H-point of the human model.

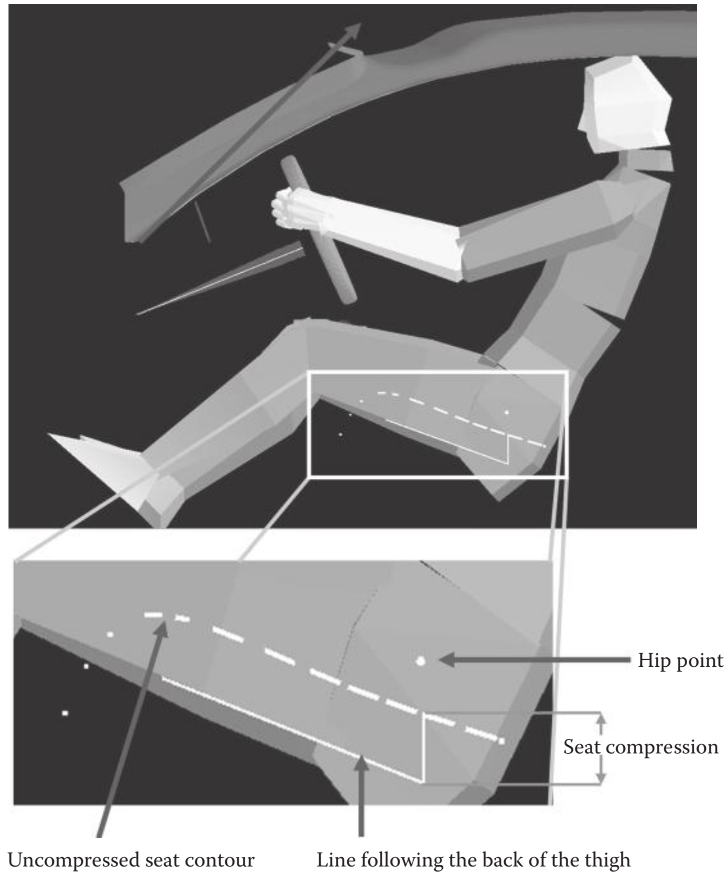


FIGURE 20.16 The method used to calculate seat compression.

Figure 20.16 shows how the seat compression is applied in the DHM process. A contour is created that represents the uncompressed seat surface. The human model is positioned using the Porter and Gyi data to allow reach to the pedals and reach to the steering wheel. The posture is then corrected to account for the seat compression by ensuring that the intersection of the line below the H-point and the line of the back of the thigh of the human model is below the uncompressed seat contour by the specified compression amount.

20.4.2.2 Fitting Trials for Minimum and Maximum Accommodated Human Models

The fitting trial process that is used to determine the minimum and maximum size of drivers that are accommodated combines the datasets defined above. A sample of digital human models is created using ADULTDATA and the A-CADRE data sources. The human models joints are automatically constrained using the Barter data. The human models are initially postured using the mean joint angle data from Porter and Gyi (see Table 20.1), with the variation from the mean posture that is forced by the driving package allowing an analysis of comfort. The hands are placed in a standardized position, known as "10 to 2," i.e., imagining the steering wheel as a clock face, the left hand placed at the ten o'clock position and the right hand is placed at the two o'clock position. This replicates the position used to capture joint data in the Porter and Gyi study. The feet are also carefully placed in the model. Initially, a 3D object of a shoe is sized and attached to the feet of the human model. The left leg is then positioned to reach to the fully depressed clutch, and the right leg is positioned to reach to the un-depressed accelerator pedal, with the heel positioned between the brake and accelerator pedals. These feet positions have been defined to represent the range of foot

TABLE 20.1
The Joint Angles of the Posture shown in Figure 20.17, Compared to the Posture Angle Data Reported in Porter and Gyi (1998)

Results for 35th Percentile Chinese Female	Joint Angle Range	Female Mean Joint Angle	Angles Found in SAMMIE
Trunk thigh angle	90–115	99	100
Knee angle	99–138	117	115
Arm flexion	19–75	40	37
Elbow angle	86–164	113	92

motion required for effective pedal use. Once the criteria of posture angles are within limits, and effective use of the steering wheel and pedals are defined, a series of detailed tests are performed as described in the following sections.

Figure 20.17, shows the smallest human model that can be accommodated by the case study vehicle, i.e., a 35th percentile Chinese female. Table 20.1 shows a comparison of the joint angle data from Porter and Gyi to the joint angles found in the posture shown in Figure 20.17. This posture was derived by starting with a 10th percentile Chinese female human model (the target defined by the manufacturer). This human model was unable to reach the pedals with the seat in the foremost position.

The human model size was then increased by five percentile increments until it was able to effectively reach the primary controls of the car with a posture that was within the joint range angles defined by Porter and Gyi. This process led to the identification of the 35th percentile Chinese female as being the minimum size that is comfortably accommodated.

Identification of the largest human model that is accommodated by the vehicle interior was a more simple process. It was found that the 99th percentile Dutch male could be accommodated by the seat and steering wheel adjustability as shown in Figure 20.18 and Table 20.2.

The minimum and maximum driver sizes that can be accommodated by the case study car have been identified on the basis of the joint constraint data and the location of the seat, pedals, and steering wheel. The next stage in the process is to test the postures and size of the human models identified by examining clearances to the steering wheel and roof line.

20.4.2.2.1 Clearance to the Steering Wheel

The explosive phase of steering wheel air bag deployment requires a certain clearance between the chest of the user and the steering wheel surface. In the cases of both the 35th percentile Chinese female and the 99th percentile Dutch male, the required 250 mm clearance was achieved. The white

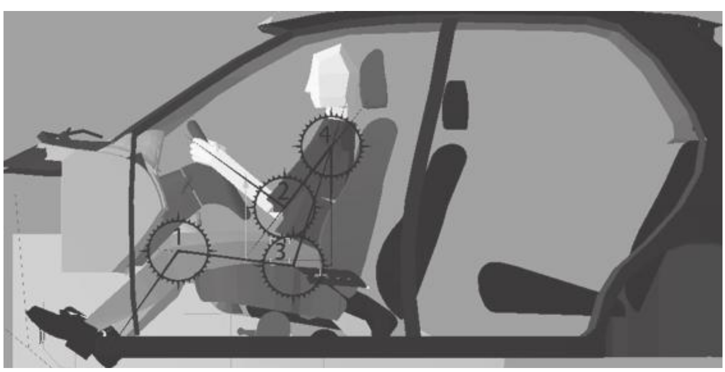


FIGURE 20.17 The minimum size of a driver that can be accommodated by the case study car.

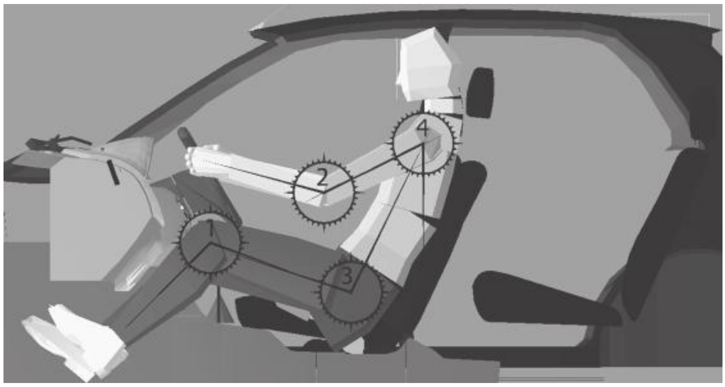


FIGURE 20.18 The 99th percentile Dutch driver accommodated in the case study car.

line between the steering wheel and chest of the human models shown in Figure 20.19 shows this clearance.

20.4.2.2.2 Head Clearance

A minimum head clearance to the roof liner of the car of 50 mm was specified by the automotive design team. The analysis showed that this was possible for the 35th percentile Chinese female, but was not possible for the 99th percentile Dutch male, as shown in Figure 20.20. It would be possible to improve head clearance for the largest male by allowing the human model to recline further in the seat, but this would require a larger range of rearward (toward the driver) steering wheel adjustability to allow for a comfortable posture for the arms while driving.

This analysis shows that the head room available for the 99th percentile Dutch male is not sufficient, and should be increased by 12 mm at least. This could be achieved by adding to the height adjustment of the seat, or by adding to the rearward adjustment of the steering wheel to support a more reclined posture for the 99th percentile Dutch male.

20.4.2.3 Reach to Handbrake, In-Car Entertainment Controls, and Heating, Ventilation, and Air Conditioning Controls

With the clearance analysis performed, the next stage in the process is to examine reach to the handbrake and dash board mounted controls. Many DHM systems allow the modification of the hand posture of the human model to represent the different types of control interactions that occur. For example, the use of single push button would be performed with the index finger stretched, and the use of rotary controls would be performed with an index finger and thumb pinch grip. Figure 20.21 illustrates that both the smallest and largest human models could effectively reach the handbrake using an appropriate hand posture. Problems with the reach to the handbrake are commonly

TABLE 20.2
The Joint Angles of the Posture Shown in Figure 20.18, Compared to the Posture Angle Data Reported in Porter and Gyi (1998)

Results for 99th Percentile Dutch Male	Joint Angle Range	Male Mean Joint Angle	Angles Found in SAMMIE
Trunk thigh angle	90–115	101	98
Knee angle	99–138	121	115
Arm flexion	19–75	50	64
Elbow angle	86–164	128	139

FIGURE 20.19 Clearances between the steering wheel and the chest of the human models.

found for small females who struggle to reach the handbrake as their arms can be blocked by the side of the seat.

Figure 20.22 shows the reach to the in-car entertainment (ICE) controls and the heating, ventilation, and air conditioning (HVAC) controls. In the case study analysis, all these controls had been well positioned and allowed comfortable reach. Reach to the various ICE and HVAC controls can generally cause problems for both large and small drivers. The seat position for large drivers can often be too far rearward to allow comfortable reach to controls. Smaller users can often struggle to reach controls that are mounted furthest from them on the dash board, and vision of the controls can be obscured by the steering wheel. This can often lead to users being forced to lean sideways or forward in order to reach controls. All controls should be within comfortable reach for the driver to avoid undue distraction from the task of safe driving.

20.4.2.3.1 Reach to the Gear Stick

The reach to the gear stick is tested by performing reach operations to the gear stick in the second gear position and the fifth gear position, which are the closest to and furthest from the driver, respectively. This allows the testing of the postures adopted for the most extended posture and the most cramped posture required for gear stick use. As with the operation of the handbrake, the use of the gear stick can be hindered by the lateral support cushions in the seat back. The testing of the 35th percentile Chinese female was successful for both positions in the case study vehicle, as shown in Figure 20.23.

The testing of the 99th percentile Dutch male was more problematic. It was found that the second gear position could be effectively reached; however, the fifth gear position could only be reached with the fingers of the right hand extended, and the right shoulder extended (Figure 20.24). Based

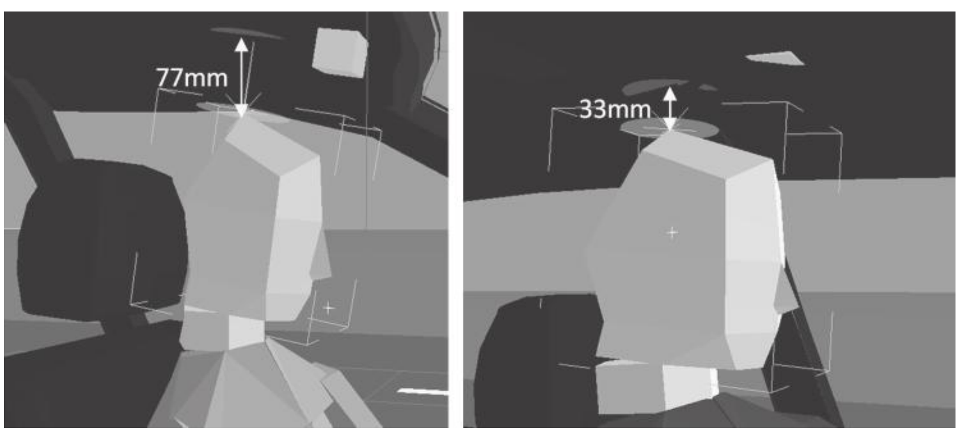


FIGURE 20.20 Clearances between the roof liner and the head of the human models.

FIGURE 20.21 Reach to the handbrake for the smallest and largest accommodated drivers.

on the joint constraint data built into the DHM system, the posture would be uncomfortable for this driver. The obvious solution would be to move the gear stick position rearward in the car. However, the amount that the gear stick location can be changed would depend on a number of design issues that relate to the engineering of the car. In this case, the result would be presented to the manufacturer with a request for the rearward movement of the gear stick by 30 mm to allow improved reach without stretching the fingers. Any new gear stick position would need to be retested with all human models.

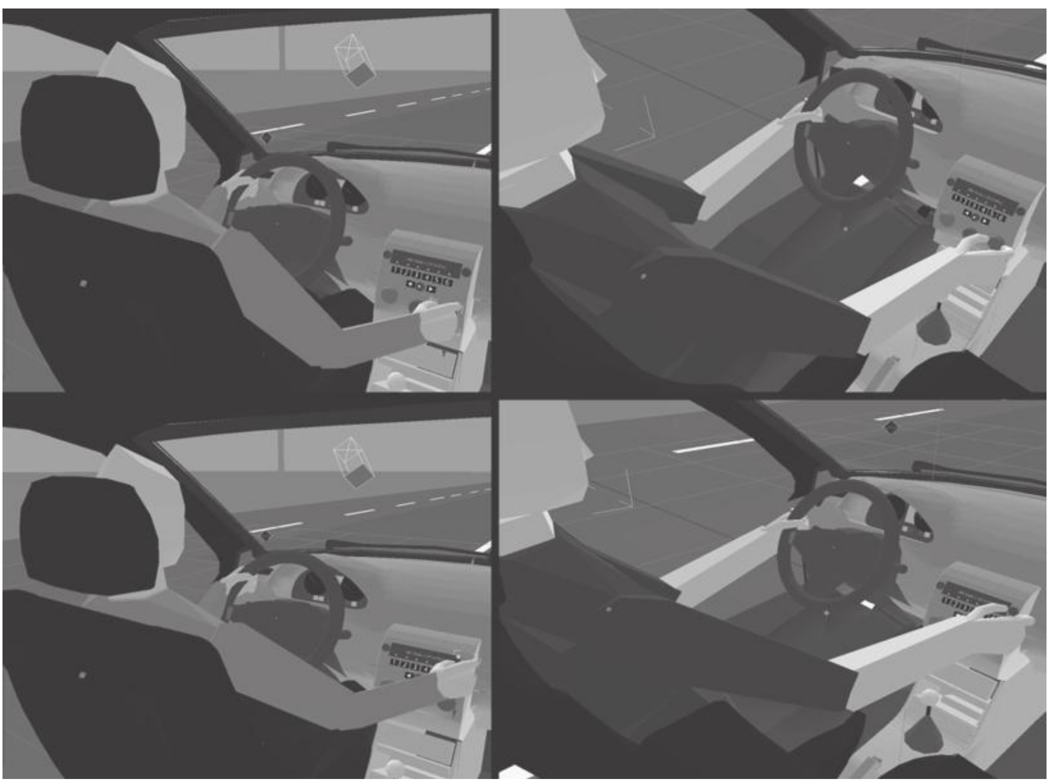


FIGURE 20.22 Reach to the ICE and HVAC controls that are farthest from the human models.

FIGURE 20.23 Use of the gear stick by the 35th percentile Chinese female.

20.4.2.3.2 Vision of Speedometer and Warning Lights

Most DHM systems provide the option of simulating the view from the eyes of the human. This is useful in determining if controls and displays are obscured by the steering wheel of an interior design. Figure 20.25 illustrates what can be seen from the eye point of the two test human models. The top of the speedometer is obscured by the steering wheel in its highest position of adjustability. The steering wheel in the car that was used as the basis for the case study had tilt adjustment only. The angle through which the steering wheel tilts was initially 4 degrees. It was found that a tilt of 9 degrees would be required to allow good visibility of the speedometer by both human models. It is generally recommended that a steering wheel with tilt and fore/aft adjust is provided in order to

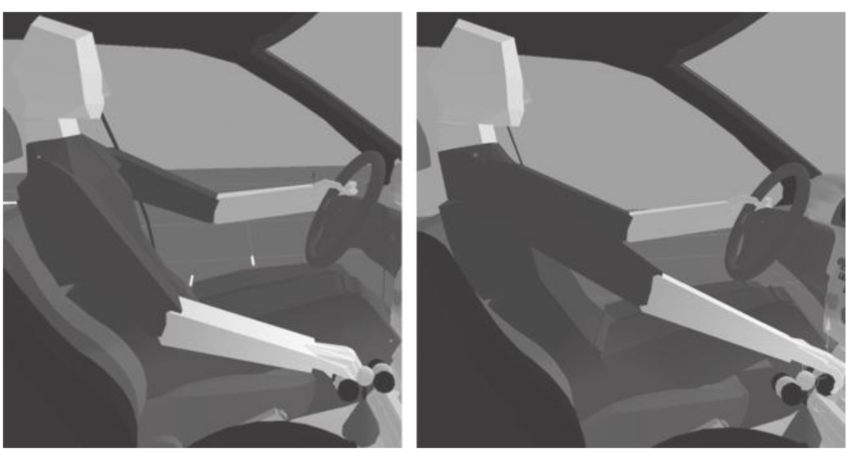


FIGURE 20.24 The difficulty for the 99th percentile Dutch male in reaching to the 5th gear location.

FIGURE 20.25 The visibility of the dials through the steering wheel in its highest adjustment setting.

allow for improved arm posture and good visibility of the dials. However, it is more expensive to provide both fore/aft and tilt adjustment, thus small cars will generally only have both adjustments on the most expensive models, if at all.

20.4.2.4 Analysis Summary

The example analysis process that has been described illustrates a number of design issues that need to be addressed before the case study car would be able to accommodate the desired population. In order to accommodate smaller Chinese females than the 35th percentile, the pedals would need to be moved rearward in the car, or adjustable pedals added. The adjustability ranges for the steering wheel that were defined using the SAE process by the manufacturer do not allow good visibility of the speedometer for the extremes of the population, and would need to be extended. The head room available for the 99th percentile Dutch male is not sufficient, and should be increased by 12 mm at least. Finally, the gear stick location cannot be comfortably reached by the 99th percentile Dutch male, with further design iterations recommended.

The results from the analysis would generally be passed back to the manufacturer, and further design iterations would be produced and tested in the DHM system. The final agreed result of the digital process would then be used to create a full-sized mock-up of the vehicle interior, which would be tested using a suitable range of real people. Ideally, this process would be developed into an integrated ergonomics evaluation process that is subsequently applied to the development of new vehicles.

20.4.3 Case Study Conclusions

The case study analysis of the small car interior has illustrated the power of DHM systems to identify design changes that could improve comfort for a large proportion of the population based on the argument of multivariate accommodation. These design changes can be implemented early in the design process, reducing the risk of poor occupant accommodation, and potentially improving the safety of users. The data that drives the DERG occupant accommodation process are based on measures taken directly from potential users of the product to allow improved accuracy in the simulation process. However, at present, the core of all DHM analyses should be the verification of design decisions using physical mock-ups and real participants where ever possible.

20.5 CONCLUSIONS

This chapter has described the set of computer-based ergonomics processes known collectively as DHM. There are a number of different DHM systems all with their own features and ways of working and yet all of them contain some basic, core functionality that supports the ability to virtually assess a CAD model during the early stages of design. These assessments can then address the fit, posture, reach, and vision of humans when interacting with a product or environment. The potential advantages of adopting such processes are significant, good ergonomics practice can be built into a design process from the early concepts, and specifications can be established to ensure that end users are accommodated to the greatest extent possible. In addition, aligning ergonomics with other design tools, such as CAD, reduces time scales and allows rapid iterations toward a solution. The automotive case study presented in this chapter illustrates some of this approach, describing a process developed by the Design Ergonomics Group at Loughborough University that embodies many years of experience in the development and use of DHM systems. In addition to illustrating a typical application of DHM, the variety of assessments that can be performed, and how these assessments can be used to drive the design of a product, the case study serves to illustrate the complexity of embedding good ergonomics into a design. It should be acknowledged that DHM tools, while increasingly sophisticated and employing ever more automated tools, are equally capable of being used to establish and confirm poor design decision making. As such, it is imperative that DHM systems are employed with a thorough understanding of all the ergonomics issues concerned with their use. In particular, this includes the nature of the data used to drive the human models, including its age and relevance to the population for which it is being designed. However, more generally, it is key that the assumptions that are made, sometimes transparently, sometimes hidden from the DHM system user, are fully understood and their impact on any assessment and ultimately on the design addressed. Finally, while DHM systems have significant benefits to offer to design, they are not a replacement for working with real people. Direct interaction between end users, a physical prototype, and members of the design team should be seen as the gold standard for determining the suitability of a design for their needs. However, appropriate use of DHM tools can ensure that when this point in the design process is reached, the design will be sufficiently mature to focus end-user input on the fine details that hopefully ensure a pleasurable experience as opposed to focusing on fundamental ergonomics issues.

REFERENCES

ADULTDATA. 1998. *The Handbook of Adult Anthropometry and Strength Measurements – Data for Design Safety*, eds. L. Peebles and B. Norris. London: Department of Trade and Industry.

Badler, N.I., Phillips, C.B., and Webber, B.L. 1993. *Simulating Humans: Computer Graphics Animation and Control*. New York: Oxford University Press.

Bittner, A.C. 2000. A-CADRE: Advanced family of manikins for workstation design. *Proceedings of the IEA 2OOO/HFES 2000 Congress,* 4:774–77. San Diego: Human Factors and Ergonomics Society. ISBN 0-945289-13-8. http://www.hfes.org/Publications/ProductDetail.aspx?ProductId=15

BS EN ISO 7250-1. 2008. Basic human body measurements for technological design: Part 1 – body measurement definitions and landmarks. London: British Standards Institute.

BS EN ISO 15536-1. 2008. Ergonomics – Computer manikins and body templates: Part 1 – general requirements. London: British Standards Institute.

BS EN ISO 15536-2. 2007. Ergonomics – Computer manikins and body templates: Part 2 verification of functions and validation of dimensions for computer manikin systems. London: British Standards Institute.

BS EN ISO 15537. 2004. Principles for selecting and using test persons for testing anthropometric aspects of industrial products and designs. London: British Standards Institute.

CAESAR. 2010. Civilian American and European Surface Anthropometry Resource. http://store.sae.org/caesar/ (accessed February 21, 2010).

Coblenz, A., Mollard, R., and Renaud, C. 1991. Ergoman: 3-D representations of human operator and man-machine systems. *International Journal of Human Factors in Manufacturing* 1:167–78.

Das, B., and Kozey, J. 1999. Structural anthropometric measurements for wheelchair mobile adults. *Applied Ergonomics* 30 (5): 385–90.

Dassault Systemes. 2010. Virtual Ergonomics Solutions. http://www.3ds.com/products/delmia/solutions/human-modeling/#vid1 (accessed February 21, 2010).

Dong, F., Clapworthy, G.J., Krokos, M.A., and Yao, J. 2002. An anatomy-based approach to human muscle modeling and deformation. *IEEE Transaction on Visualization and Computer Graphics* 8:154–70.

DI-Guy. 2010. http://www.diguy.com/diguy/ (accessed February 21, 2010).

Dreyfus, H. 1964. *The Measure of Man: Human Factors in Design.* London: Architectural Press.

Elias, H.J., and Lux, C. 1986. Gestatung ergonomisch optimierter Arbeitsplatze und Produkte mit Franky und CAD [The design of ergonomically optimized workstations and products using Franky and CAD]. *REFA Nachrichten* 3:5–12.

ESI Group. 2010. http://www.esi-group.com/ (accessed February 21, 2010).

Fortin, C., Gilbert, R., Beuter, A., Laurent, F., Schiettekatte, J., Carrier, R., and Dechamplain, B. 1990. SAFEWORK: A micro-computer aided workstation design and analysis, new advances and future developments. Genicom Inc., Montreal Quebec.

Goswami, A., Ganguli, S., and Chatterjee, B. 1987. Anthropometric characteristics of disabled and normal Indian men. *Ergonomics* 30 (5): 817–23.

Grobelny, J., Cyewski, P., Karwowski, W., and Zurada, J. 1992. APOLIN: A 3-dimensional ergonomic design and analysis system. In *Computer Applications in Ergonomics, Occupational Safety and Health*, eds. M. Mattila and W. Karwowski, 129–35. Amsterdam: Elsevier Science.

Hobson, D., and Molenbroek, J. 1990. Anthropometry and design for the disabled: experiences with seating design for the cerebral palsy population. *Applied Ergonomics* 21 (1): 43–54.

Human Solutions. 2010. http://www.human-solutions.com/ (accessed February 21, 2010).

Kloke, W.B. 1990. WERNER: A personal computer implementation of an extensive anthropometric workplace design tool. In *Computer-Aided Ergonomics*, eds. W. Karwowski, A.M. Genaidy and S.S. Asfour, 57–67. London: Taylor & Francis.

Kuusisto, A., and Mattila, M. 1990. Anthropometric and biomechanical man models in computer-aided ergonomic design structure and experiences of some programs. In *Computer-Aided Ergonomics*, eds. W. Karwowski, A.M. Genaidy and S.S. Asfour, 104–14. London: Taylor & Francis.

LAA. 2010. Laboratory of Applied Anthropology. http://www.biomedicale.univ-paris5.fr/LAA/eergoman.htm (accessed February 21, 2010).

Launis, M., and Lehtelä, J. 1990. Man models in the ergonomic design of workplaces with the microcomputer. In *Computer-Aided Ergonomics*, eds. W. Karwowski, A.M. Genaidy and S.S. Asfour, 68–79. London: Taylor & Francis.

Marshall, R., Case, K., Porter, J.M., Sims, R.E., and Gyi, D.E. 2004. Using Hadrian for eliciting virtual user feedback in 'Design for All'. *Journal of Engineering Manufacture. IMECHE Proceedings Part B* 218 (B9): 1203–10.

Marshall, R., Case, K., Summerskill, S.J., Sims, R.E., Gyi, D.E., and Davis, P.M. 2009. Virtual task simulation for inclusive design. In *Lecture Notes in Computer Science: Proceedings of the Second International Conference*, ed. V.G. Duffy, 700–9, ICDHM 2009. Held as part of HCI International 2009, San Diego, CA, July 19–24. Berlin: Springer.

McDaniel, J.W. 1990. Models for ergonomic analysis and design: COMBIMAN & CREW CHIEF. In *Computer-Aided Ergonomics*, eds. W. Karwowski, A.M. Genaidy and S.S. Asfour, 138–56. London: Taylor & Francis.

NexGen Ergonomics Inc. 2010. http://www.nexgenergo.com/ (accessed February 21, 2010).

NIOSH. 2010. National Institute for Occupational Safety and Health: Revised NIOSH Lifting Equation. http://www.cdc.gov/niosh/docs/94–110/ (accessed February 21, 2010).

OWAS. 2010. Ovako Working Analysis System. http://turva1.me.tut.fi/owas/ (accessed February 21, 2010).

Paquet, V., and Feathers, D. 2004. An anthropometric study of manual and powered wheelchair users. *International Journal of Industrial Ergonomics* 33 (3): 191–204.

Parkinson, M., and Reed, M. 2006. Optimizing vehicle occupant packaging. *SAE Transactions: Journal of Passenger Cars–Mechanical Systems* 115.

PeopleSize. 1998. Reference visual anthropometry software [online]. Open Ergonomics. http://www.openerg.com/psz/index.html (accessed February 21, 2010).

Pheasant, S.T. 1996. *Bodyspace: Anthropometry, Ergonomics and the Design of Work*, 2nd ed. London: Taylor & Francis.

Porter, J.M., Case, K., and Freer, M.T. 1996. SAMMIE computer aided ergonomics. *Co-Design* 7–8:68–75.

———. 1999. Computer aided design and human models. In *Handbook of Occupational Ergonomics*, eds. W. Karwowski and W. Marras, 479–500. Boca Raton, FL: CRC Press.

Porter, J.M., Case, K., Marshall, R., Gyi, D.E., and Sims, R.E. 2004. Beyond Jack and Jill: Designing for individuals using HADRIAN. *International Journal of Industrial Ergonomics* 333:249–64.

Porter, J.M., Case, K., and Freer, M.T. 2009. Four decades of SAMMIE. In *Ergonomics at 60: A Celebration*, 12–13. Loughborough: The Ergonomics Society.

Porter, J.M., and Gyi, D.E. 1998. Exploring the optimum posture for driving comfort. *International Journal of Vehicle Design* 19 (3), 255–66.

Porter, J.M., and Porter, C.S. 2001. Occupant accommodation: An ergonomics approach. In *An Introduction to Modern Vehicle Design*, ed. J. Happian-Smith, 233–76. London: Butterworth-Heinemann.

Porter, C.S., and Porter, J.M. 1997. The interface between ergonomists and product designers. In *Proceedings of the 13th Triennial Congress of the International Ergonomics Association*, eds. P. Seppala, T. Loupajarvi, C.H. Nygard and M. Mattila, 240–42. Tampere, Finland: Finnish Institute of Occupational Health.

Post, F.H., and Smeets, J.W. 1981. ADAPS: Computer aided anthropometrical design. *Tijdschrift voor Ergonomic* 6 (4), 11–18 (in Dutch).

Robinette, K.M., Daanen, H., and Paquet, E. 1999. The CAESAR project: A 3-D surface anthropometry survey. *Proceedings of the second International Conference on 3-D Digital Imaging and Modeling*, ed. B. Werner, 380–86. Ottawa, Canada.

RULA. 2010. Rapid Upper Limb Assessment. http://www.rula.co.uk/ (accessed February 21, 2010).

SAMMIE CAD. 2010. SAMMIE CAD ergonomics consultancy website, home of the SAMMIE (System for Aiding Man Machine Interaction Evaluation) DHM system. http://www.sammiecad.com (accessed February 21, 2010).

Santos Human Inc. 2010. http://www.santoshumaninc.com/ (accessed February 21, 2010).

Sheldon, W.H. 1954. *Atlas of Men: A Guide for Somatotyping the Adult Male at all Ages.* New York: Harper.

Siemens. 2010. Siemens PLM software: Jack and process simulate software. http://www.plm.automation.siemens.com/en_us/products/tecnomatix/assembly_planning/jack/index.shtml (accessed February 21, 2010)

SizeUK. 2010. *UK national sizing survey*. http://www.sizeuk.org (accessed February 21, 2010).

SAE. 1995. Manikins for use in defining vehicle seating accommodation. SAE J826. SAE standard, Vehicle Occupant Restraint Systems and Components.

SAE. 2010. H-Point Machine (HPM-II) Specifications and Procedure for H-point Determination – Auditing Vehicle Seats. SAE j4002. SAE standard, Vehicle Occupant Restraint Systems and Components, January 2010.

Stumpf, B., Chadwick, D., and Dowell, D. 2001. The Anthropometrics of Fit: Ergonomic Criteria for the Design of a New Work Chair. Herman Miller White paper. http://www.hermanmiller.co.uk/our-business/white-papers/ (accessed February 21, 2010).

TASS. 2010. http://www.tass-safe.com/en/home (accessed February 21, 2010).

TC^2. 2010. Textile/Clothing Technology Corp. http://www.tc2.com/ (accessed February 21, 2010).

Treleaven, P. 2007. How to fit into your clothes: Busts, waists, hips and the UK National Sizing Survey. *Significance* 4 (3): 113–17.

Vassilev, T., and Spanlang, B. 2002. A mass-spring model for real time deformable solids. *East-West-Vision* (September).

Vitronic. 2010. VITUS 3D body scanner. http://www.vitronic.de/en/bodyscannen/ (accessed February 21, 2010).

Wegner, D., Chiang, J., Kemmer, B., Lamkull, D., and Roll, R. 2007. Digital human modelling requirements and standardization. In *Proceedings of the SAE 2007 Digital Human Modelling for Design and Engineering Conference and Exhibition*, 1–8. SAE Paper No 2007-01-2498, Seattle, WA, June 2007.

Westerink, J., Tragter, H., Van Der Star, A., and Rookmaaker, D.P. 1990. TADAPS: A three-dimensional CAD man model. In *Computer-Aided Ergonomics*, eds. W. Karkowski, A.M. Genaidy, and S.S. Asfour, 90–103. London: Taylor & Francis.

21 Digital Human Modeling in Product Evaluation

Maria Lucia Leite Ribeiro Okimoto

CONTENTS

21.1 INTRODUCTION

In the last 30 years, software technology representation of human beings has increased. So it is in this context that representations of human beings are understood as those generated by computers using computer-aided design (CAD) or similar software, known as digital human models (DHM). According to Reed (2009), many of the original human modeling tools dating from the 1970s were developed by the U.S. military and its contractors for cockpit design.

Product design is moving away from a reactive approach, in which jobs that cause injuries are modified, to a proactive approach that emphasizes assessing each job for feasibility and safety as the workplace and processes are designed (Reed 2009). In this proactive context suggested by Reed, plus the wide range of human characteristics, proportion, anthropometry, ability, and strength, ergonomics is often the most difficult variable to factor into the early stages of the design process. Ergonomic considerations are often not given priority until relatively late in the design process, coinciding with product's launch in the market, when the users have difficulty operating and maintaining them. As a result, in other cases, users may even be injured by poor ergonomic design. Technology can help us through virtual ergonomics, reducing the gap between functional design and design appropriate to human factors. This technology can enable users to create and manipulate virtual 3D manikins to search for the interactions between users and the product.

The largest area of application of the DHM technology is the automotive industry, because the process of designing a new vehicle has to meet a large number of requirements and follow the standards of the Society of Automotive Engineers (SAE). In vehicle design processes, the DHM is used in conjunction with traditional CAD systems, and it can aid product designers in clearly understanding the human–product interactions, thereby enabling them to evaluate the human friendliness of a product and make appropriate design modifications in the early design stages. Now to meet the vehicle design and the SAE standards, the CAD systems today have to include many standardized parameters related to vehicle interior geometry, e.g., the location of the H-point. We can notice that the application of ergonomic methodologies to vehicle design processes is becoming increasingly important. The DHM is used in ergonomic analyses such as motion capture and simulation, performance measurement, reach-capability check, and visibility check. For example, in the product design, human factors such as positioning, comfort, visibility, reaching, grasping, ingress, and egress can all be evaluated. Furthermore, we have a system in which we can estimate the layout, workflow throughput, system accessibility, lifting requirements, etc. Virtual ergonomics also offers solutions for defining human activities, such as walking, picking, placing, climbing, etc. The simulated manikin can perform activities from one posture to another, pick up objects and place them in another location.

In vehicle design, the DHM can be used to assess many design concerns. For example, we can examine if the seat adjustability will allow a wide range of users to reach all the needed controls. We can obtain optimized interior design parameters. The design process using this human-centered CAD system can be used as a general purpose tool for designing any other product. The important role of the DHM in the design process is in the prototype phase; expensive physical mockups are being replaced by virtual prototypes, which can quickly simulate the use of different types of manikins with different percentiles, 5th, 25th, 50th, 95th, etc., male and female. We can change the manikin's data (e.g., stature, weight, leg length, etc.) and we can build it from similar body dimensions of a real person.

The continuous uses of the DHM in the evaluation of consumer products is a fact, because organizations need a way to accurately and easily simulate the interface between humans and a product or system in the earliest stages of the design. The DHM can improve the performance of the project, save time and money, improve manufacturing efficiency, and reduce or eliminate physical simulations.

But, as described by Lockett et al. (2005) and Lämkull, Hanson, and Örtengren (2009), DHM tools are complex and using them requires good expertise in different fields. It is necessary to know ergonomics and also to have CAD skills and a detailed knowledge of the various features of the product being designed and/or evaluated. Therefore, the introduction of virtual ergonomics in design education is necessary. Lämkull, Hanson, and Örtengren (2009) emphasize the need to have expertise in ergonomics, which is needed to properly analyze and apply judgments to the results. Thus, users with different backgrounds should work in cooperative efforts with these tools.

21.2 CHARACTERISTICS OF DIGITAL HUMAN MODELING

Representations of the DHM are called "manikins" and they can have two- or three-dimensional (3D) representations of the human form. In the past, DHMs were mainly used for graphical animation. Now, DHMs are becoming widely used in the evaluation of ergonomic products. The most widely used are the 3D DHMs, which try to represent human body size and shape for design. This software package enables designers to visualize the effectiveness of a design before a physical prototype is built. There are several software packages, but the most popular in industries are: Jack, a famous DHM used in the UGS CAD system; SafeWork, a virtual human model used in the CATIA CAD system; and RAMSIS, developed by Techmath. Actually, some software allows designers to import their 3D CAD models into a virtual environment. In the engineering field, DHMs are used in the ergonomic analysis of workplaces and in product design. In addition, they are used in biomechanical analysis, and sports medicine also uses DHMs to evaluate the performance of athletes.

Jung et al. (2009) categorizes DHMs into several groups according to their uses and functions: DHMs in CAD environments, and dedicated models for biomechanical analysis and research models.

21.2.1 Digital Human Models in Computer-Aided Design Environments

These DHMs are mostly used in the following studies: human size scaling, posture setting, motion analysis, reach analysis, and vision analysis. The main advantage of using DHMs in CAD environments is that DHMs can be used at the design stage, which is the earliest stage in the product manufacturing process.

Jung et al. (2009) also describes some disadvantages, such as the lack of a realistic human appearance and oversimplified kinematics structure; their posture manipulation functions have to be improved because some DHMs in CAD have limited optimal posture prediction algorithms or manual posture settings.

21.2.2 Dedicated Models for Biomechanical Analysis

Many biomechanical researchers have developed their own models according to their research interests. These models have been developed for specific purposes. For example, SIMM is a software system that includes a scalable human model and a motion capture function as well as inverse and forward dynamics analysis modules, and is used for clinical purposes. AnyBody is a musculoskeletal simulation software, which adopts an inverse dynamic-based analysis. LifeMod is an add-on program in ADAMS and is suitable for the analysis of products or existing mechanical systems.

21.2.3 Research Models

The Center for Human Modeling and Simulation (HMS) at the University of Pennsylvania has developed a realistic human motion generation algorithm, which is implemented in Jack. The Center for Ergonomics at the University of Michigan has developed the 3D Static Strength Prediction Program (3D SSPP). The Center for Computer-Aided Design at the University of Iowa has developed a virtual human model, named Santos, under the Virtual Soldier Research Program. Santos is an intelligent avatar with realistic biomechanical abilities. Most of these research-based human models provide the theoretical background for commercial CAD-integrated human models.

21.3 HOW DIGITAL HUMAN MODELING IS USED IN PRODUCT DESIGN

The human simulation (manikin) with attributes can be inserted into a designer's 3D graphic rendering of proposed work environments. Firstly, before beginning the design, we recommend the designers to observe their Guidelines for Using Anthropometric Data in Product Design (HFES 300 Committee 2004), which can be integrated in the process of the design. Garneau (2009) describes methods, according to HFES 300, for using anthropometry in ergonomic design, with an emphasis on products with an adjustable dimension. It suggests a five-stage process for ergonomic design: (1) define the problem and relevant measures, (2) define the target audience, (3) identify the database and relevant considerations, (4) select cases (boundary manikins), and (5) apply cases to the design. Step 1 of the process, defining the problem and the relevant measures, is important for determining the type(s) of anthropometric variability under consideration for the artifact. Steps 2 and 3 of the process define the potential users of the artifact and quantify the dimensional variability apparent in those users. Often, databases of standard anthropometric data are used to represent the set of potential users, and an overview of commonly used databases is presented next. Steps 4 and 5, as stated, refer specifically to boundary manikins.

Chaffin (2007) reported that the designer is first required to specify the population segment, or relevant group attributes of concern, such as stature, body weight, gender, age, and so forth. The author then emphasizes that the designer must position the representative manikin in the posture that the designer believes best represents the functional postures of concern. Some inverse kinematics

(IK) algorithms are normally provided as part of the manikin's supporting software to assist the designer in choosing the appropriate postures for analysis. Most of the DHM software has simple menus that can be used to create standard 5th, 50th, and 95th percentile, male and female manikins. From this, users then have access to manikin structures offering independent links and degrees of freedom with limits of joint mobility, permitting precise simulation of actual human capabilities in a wide range of acceptable situations. But a serious problem observed by Chaffin (2007) is that designers were often highly challenged when predicting how a person of certain anthropometric characteristics should be positioned in the virtual workplace, especially if dynamic motions were to be simulated. If the designer does not have a profound understanding of biomechanics as well as the time to experiment with alternative postures and motion scenarios, this is a very serious deficiency, as it has been shown that small errors in posture can result in very large errors in the predicted population strengths.

Chaffin (2001, 2007) believed that one of the most important features of a DHM was that the human simulations and associated graphics allowed both product and process designers to better understand the potential problems and associated risks a particular population subgroup could have when operating or servicing a proposed design.

For evaluation of associated user's risks in the product, the designer must know some tools in the ergonomic package, such as: 3D biomechanics tools that calculate torque, load, and shear; analyze lifting, lowering, and carrying tasks using NIOSH 81 and 91 equations; evaluate push and pull tasks using SNOOK and CIRIELLO equations; and evaluate RULA, for arm position assessment with the ability to customize RULA specifications. With this knowledge, it will be easy to analyze, both qualitatively and quantitatively, all aspects of a user's posture. Whole body and localized postures can be examined, scored, and integrated to determine user comfort, safety, strength, and performance when interacting with a product in accordance with published comfort databases. Static strength can be analyzed, along with comfort and joint analysis and fully articulated pelvic, neck, spine, shoulder, and hand models.

21.4 SOME EXAMPLES OF DHM APPLICATION IN COMPUTER-AIDED DESIGN SYSTEM

To better understand how DHM tools can improve design while reducing or eliminating the need for physical simulations and reducing injuries, we present some examples developed in the Ergonomic and Usability Laboratory of the Federal University of Paraná, Brazil.

21.4.1 Case: Radial Drill

This section aims to evaluate loads and the work position in the use of a radial drill. Twelve volunteers (average height of 1.735 m and s.d. = 8.52), received marks in the joint centers of shoulder, elbow, wrist, and hip, simulating the use of the drill. Images had been collected using a digital camera. The angular references of the joints had been located and was built the digital manikin to perform analyses of RULA and biomechanics through the CATIA software (V5R16). The data had been tabulated and applied to the Spearman correlation was considered statistically significant when $p < 0.05$. The strong correlation, $p < 0.965$, occurs between the variables angle of trunk and moment of force in L4/L5; angle of trunk and force of compression on L4/L5, $p < 0.951$; and the correlation between the angle of trunk and strength of compression, bending, in moments of force in L4/L5 found a $p < 0.958$. Figure 21.1a–c shows the binocular vision of the DHM of the three people, each with different height and weight.

The results obtained after implementation of the proposed method shows that the process of constructing manikins from data collected through images, proved to be efficient and easy to use. It was noted that a higher amount of markings could facilitate the construction of the manikin, and it

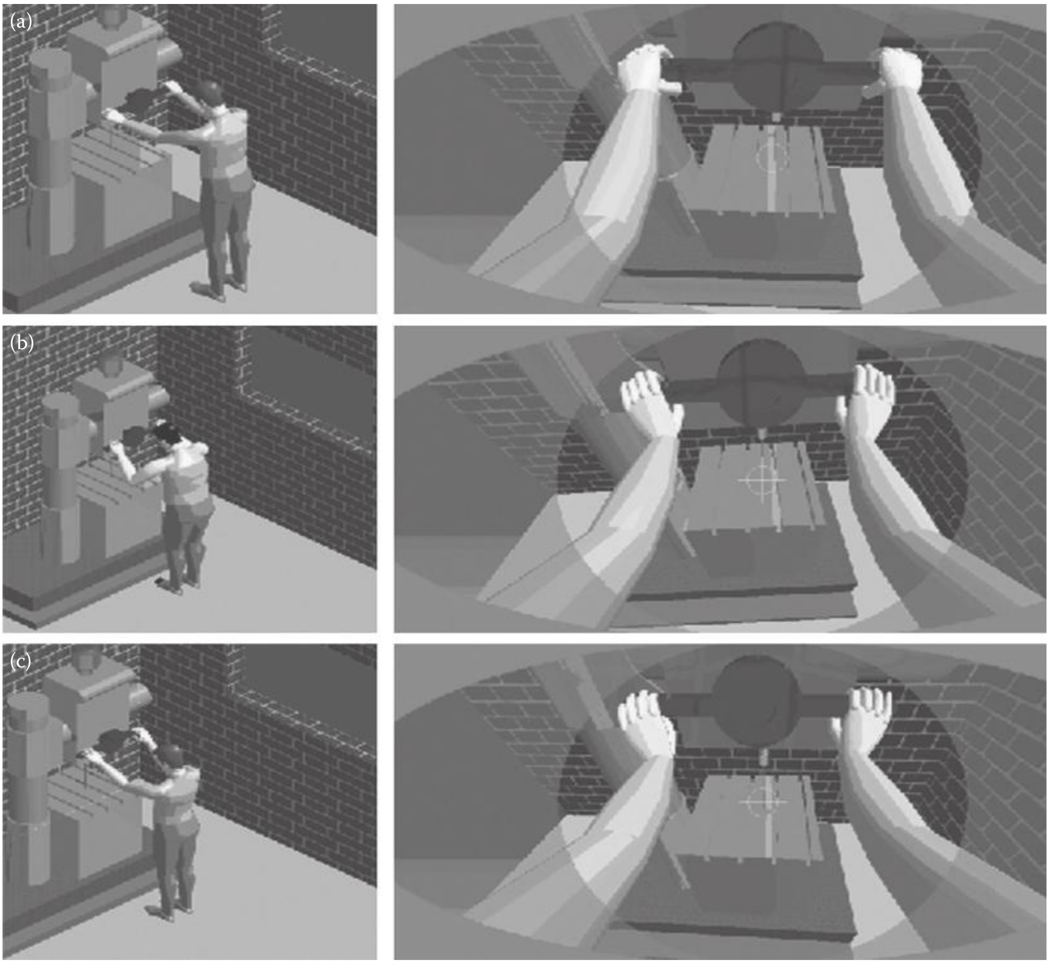


FIGURE 21.1 (a–c) Results of simulation use of the radial drill for different users and binocular vision.

was noticed that the sample was not sufficient to elicit meaningful data, serving only to demonstrate a trend. It was observed that the use of virtual manikins accelerates the process of data collection of postural analysis, RULA, and especially of biomechanics. The use of manikins favors even simulation changes in the product evaluated, as well as postural demands that each suggested change in the product could adversely affect the user. After analyzing the results, we then realized that the drill in question was developed for people within the 5th percentile; men shorter than 1.59 m found the drill more comfortable to use. We concluded that this product was not designed to meet the vast majority of its users.

21.4.2 Case 2: Carts to Carry Loads

This study is a descriptive study to assess the task of pushing and pulling carts to carry loads used in the industrial sector. For data collection, in order to measure the muscle strength of the users, a load cell was used, measured in various horizontal surface and slope postures. For the analysis of the situation, CATIA VR15 software simulations were also made from the entry of data obtained in the real situation. For the DHM simulation, the following ergonomics packages were used: CATIA VR15, Ergonomics Analysis, Activity Analysis, Biomechanics Analysis, and Push-Pull Analysis. For the study of DHM simulation, the following steps were performed: (1) construction of the

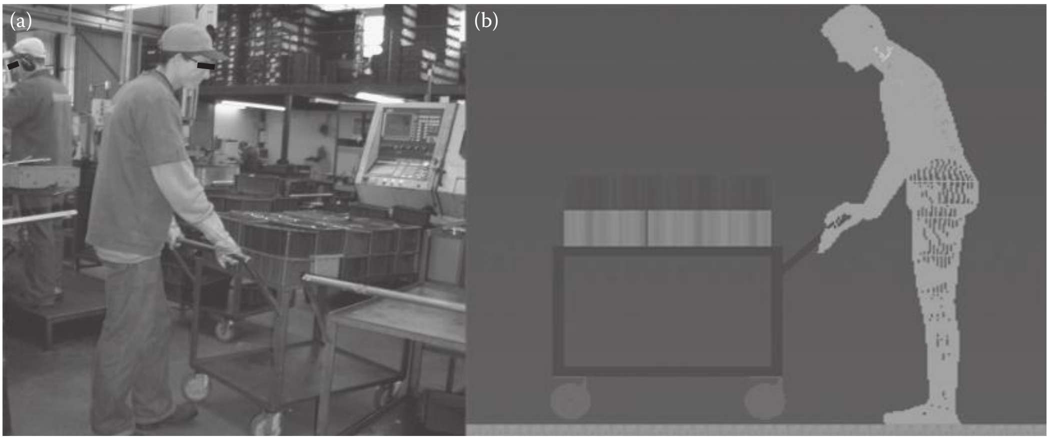


FIGURE 21.2 Use of carts to carry loads. (a) Real situation. (b) An ergonomic evaluation of the simulated situation.

product in the CATIAVR15 (mechanical design); (2) reproduction of anthropometric dimensions of height and weight of the users in the software package (human builder); and (3) adding the average load applied to the operator's hand, according to the direction of the component and application of ergonomic analysis module and interpretation of results, allowing the viewing levels of compatibility with the load in the effort backbone between the L4 and L5. Figure 21.2 gives the application of the real situation and the ergonomic analysis simulation in the biomechanics singular action analysis and push pull analysis with load definition.

21.4.3 Case 3: Accessibility in Wheelchair

The purpose of this study was to evaluate the accessibility of social housing for a low-income family in the Sambaqui Village in Curitiba, Brazil. After the first stage of data collection in the house was chosen, it was drafted in CATIA software VR16, the environment of the house with the dimensional fidelity of the real situation. Then the furniture, wheelchair, and virtual human model were built, as shown in Figure 21.3. Equipment present in the house, including window frames, doors, dishes, and household objects were also added. Through this detailed environment, will be possible to anticipate many things that disabled people will face daily. Next, simulations of movement of the wheelchair within this environment were generated through a manikin where situations of daily activities were presented as, e.g., access to locks, the use of the bathroom, and the opening of doors and drawers in existing furniture (Figure 21.3).

These simulations were identified and indicated the difficulties in using the product. We conclude that the use of DHM software allowed an ergonomic analysis in a virtual environment of the residence, facilitating a more detailed assessment on accessibility issues in the social housing project, than the direct and indirect methods of observation.

21.5 CONCLUSION

It is important to build powerful tools in order to evaluate all the ergonomic aspects of a product, starting from the early stage of its conceptual definition. These tools can be very simple, e.g., two-dimensional software programs, or more complex programs based on human modeling with a 3D representation and with ergonomic analysis modules. The integration of the human model into the CAD systems allows designers and engineers to have a global view of product interaction before use. However, this requires good expertise in how to use the DHM tool and also in how different products should perform.

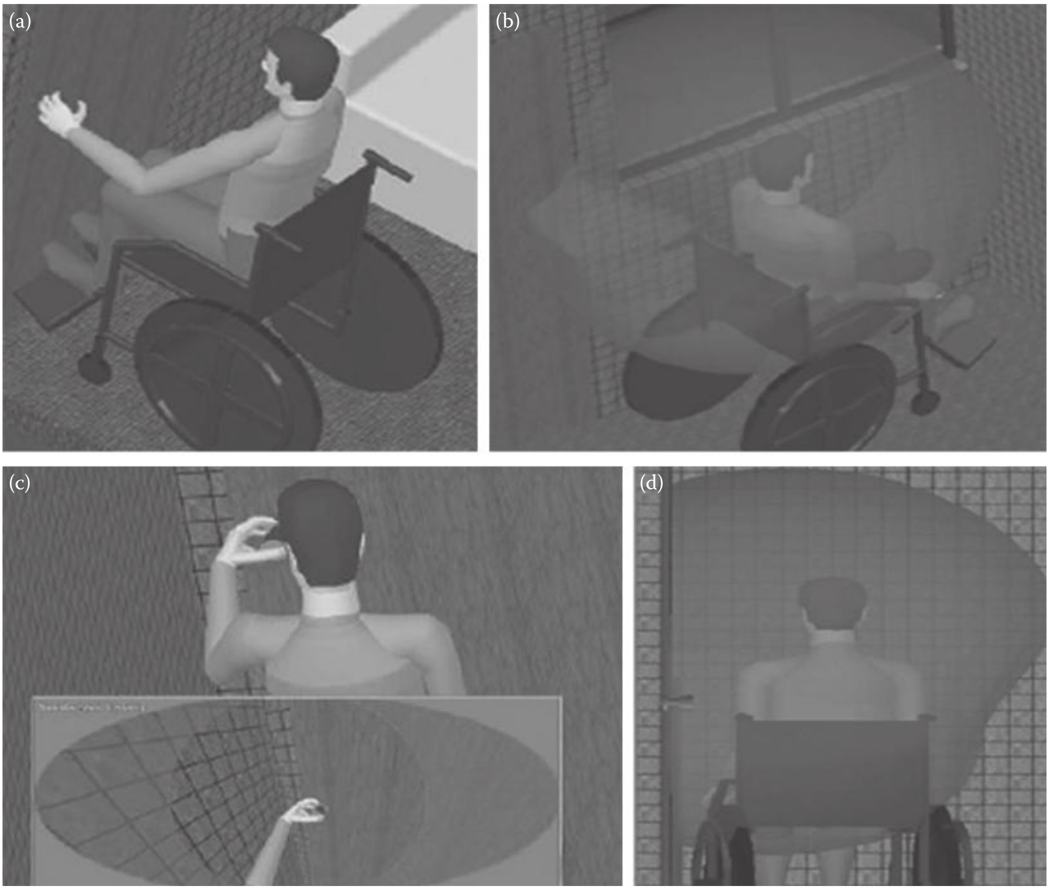


FIGURE 21.3 Layout of the accessibility analysis of the wheelchair (a–d).

REFERENCES

Chaffin, D.B. 2001. Digital Human Modeling for vechicle and workplace design. Warrendale, PA: SAE International.

Chaffin, D.B. 2007. Human motion simulation for vehicle and workplace design. *Human Factors and Ergonomics in Manufacturing* 17 (5): 475–84.

Garneau, C.J. 2009. Investigation of accommodation for products designed for human variability. PhD Diss. Pennsylvania State University.

HFES 300 Committee. 2004. *Guidelines for Using Anthropometric Data in Product Design*. Human Factors and Ergonomics Society, Santa Monica, CA.

Jung, M., Cho, H., Roh, T., Lee, K. 2009. Integrated framework for vehicle interior design using digital human model. *Journal of Computer Science and Technology* 24 (6): 1149–61.

Lämkull, D., Hanson, L. and Örtengren, R. 2009. A comparative study of digital human modelling simulation results and their outcomes in reality: A case study within manual assembly of automobiles. *International Journal of Industrial Ergonomics* 39:428–41.

Lockett, J., Kozycki, R., Gordon, C., and Bellandi, E., 2005. Porposed integrated human figure modeling analysis approach for the Army's future combat systems. In: Military Vehicle Technology (SP-1962). Warrendale, PA: SAE International.

Reed, M.P. 2009. Modeling ascending and descending stairs with the Human Motion Simulation Framework. Technical Paper 2009-01-2282. *Proceedings of the 2009 SAE Digital Human Modeling for Design and Engineering Conference*. Warrendale, PA: SAE International.

22 Three-Dimensional Foot Imaging: Axial Alignment Theory in Footwear Design, Fit, and Function

Anette Leonor Telmo Thompson, Bernhard Zipfel, and Saramarie Eagleton

CONTENTS

22.1 INTRODUCTION

From the earliest times, mankind crafted foot coverings of hide, skins, wood, bark, and reeds to cover the feet. From these rough, irregular shoes, to modern developments in technology and ergonomic footwear design, mankind continues to search for the ideal shoe—a shoe offering comfort and fit, supporting the foot in weight bearing, locomotion, and support (Hawes and Sovak 1994; Rossi 2003).

22.2 SHOE FIT: AN INTERACTION OF FORM AND FUNCTION

Regardless of how well a shoe is crafted, it may cause the wearer discomfort if the fit is incorrect. The dictum *form ever follows function* was coined by an American architect, Louis Sullivan, in 1896 to describe the design of man-made objects as an expression of the natural world (Sullivan 1947). The form of footwear that follows the function of the foot is integral to good shoe fit.

To explore the concept of fit, factors relating both to the foot and the shoe should be considered. One definition of fit is the “ability of the shoe to conform to the size, width, shape and proportions of the foot” (Rossi 2000, 63). Another definition is that fit is the sizing that allows for proper alignment and foot function inside the shoe (Rossi 2000). Wunderlich and Cavanagh (2001) support the statement by Miller and Redwood (1989) that an acceptable fit can be obtained by matching the footwear to the foot size and shape. It follows that accurate foot measurement and knowledge of foot function are both important in fit.

For proper foot function, some areas of the foot need a snug fit to the shoe while other areas of the foot require clearance from the shoe. Poor fit is a consequence of both excessive tightness as well as excessive clearance (Lord and Pratt 1999). For a shoe to follow the function of the foot, it should “grip” the foot in two places: one that traverses the top of the instep of the foot, and the other across the back of the heel. Footwear lacking either one of these two principal means of grip will always conscript irregular foot function in order to keep the footwear on the foot. For example, open back footwear, such as mules, prompt unconscious clawing of the toes and abnormal firing of muscles in the foot and leg, altering normal gait. Attractive low cut pumps that reveal “toe cleavage” result in the same toe clawing and abnormal foot function. There is evidence that footwear constrains the natural barefoot motion of the foot (Kurz and Stergiou 2003; Hardin, Van den Bogert, and Hamill 2004; Kadambande et al. 2006; Morio et al. 2009).

22.3 IMPORTANCE OF THREE-DIMENSIONAL ANTHROPOMETRIC POPULATION MEASUREMENTS

Whether designing a new shirt or a pair of shoes, accurate body measurement data are critical to produce a superior and cost-effective product (Parham, Gordon, and Bensel 1992; Robinette, Daanen, and Paquet 1999; Ergotech 2006).

Just as high fashion couture utilizes a dressmaker’s mannequin in developing a dress design, shoe designers use lasts to provide working models of a typical foot. The single most important factor about the shape of the last is that it should match the shape of the foot that the shoe is intended for (Fuller 1994).

As late as 1900 in North America, foot studies had little impact on the actual process of last making (Cavanagh 1980). In the last century, however, foot measurement surveys were undertaken in North America, Europe, and Asia, often in collaboration with the footwear industry, to promote cooperation between last and shoe manufacturers, with the objective of improving fit (Baba 1975; Kouchi 1995; Kusumoto et al. 1996; Hawes et al. 1994; Miller and Redwood 1989; Liu et al. 1999).

Current researchers have found that measurement data are outdated. Anthropometric studies should be conducted regularly over the course of time (Smith and Norris 2004; Thompson 2006). Several morphometric (or measurement) studies have discovered ethnic differences in foot morphology, endorsing the concept of unique shoe lasts (based on different measurement data) for different populations (Hawes et al. 1994; Anil et al. 1997; Baba 1975; Benard and Stephens 1979; Thompson and Zipfel 2005; Thompson 2006). There are not only ethnic differences in foot morphology, but also rapid changes in foot measurements within the same population over quite short periods of time. For example, the Civilian American and European Surface Anthropometry Resource (CAESAR) project showed that leg length has grown faster in relation to the growth of the trunk (Robinette, Daanen, and Paquet 1999).

While sports footwear manufacturers conduct substantial research into foot function, less research is conducted on populations who wear general purpose or fashion footwear for more hours a day than they do sports shoes.

Society ascribes a cosmetic or decorative fashion value to footwear (Lord and Pratt 1999; Seale 1995; Arlen 1984). During the last decade, economic factors have resulted in globalization of the footwear industry, and fast-cycle manufacturing in lower-cost countries in Asia. Automated manufacture of ever-changing seasonal shoe ranges by technically skilled manufacturers who lack training and fundamental knowledge of foot anatomy, morphology, and function, often results in poorly fitting footwear.

22.4 IMPORTANCE OF FOOTWEAR FIT TO HEALTH

Fit is inextricably linked to foot health in both non-diabetic and diabetic populations (Chantelau and Haage 1994; Chantelau and Gede 2002; Nancarrow 1999; Macfarlane and Jeffcoate 1997). Footwear used to support an upright body for a working day must fit well, as well as provide shock absorption against ground reaction forces (GRF) from rigid surfaces (Klenerman, Nissen, and Baker 1976; Johnson 1994).

Clinically, the function of a shoe has been described as a protection from hard surfaces; from trauma such as knocks and scratches; and from extremes of temperature and moisture (Cheskin 1987; Lord and Pratt 1999; Trinkaus 2005). Prevention of deformity has been described as a further "function" of the shoe (Jackson 1990).

In reality, ill-fitting footwear can cause foot pathology such as blisters, corns, calluses, and toenail deformities (Stewart 1972; Mantaura and Bryant 1989; Dawber, Bristow, and Mooney 1996). In a study on a sample of South African women, 80% of participants ascribed foot pathology to their footwear (Thompson and Zipfel 2005). This finding prompted the first 3D foot anthropometric study in Africa in 2005 (Thompson 2006). Furthermore, there is some evidence that footwear may restrict normal foot motion and could be a contributing factor in the development of permanent bony forefoot pathologies, such as bunions, stress fractures, and arthritis (Kadambande et al. 2006; Zipfel and Berger 2007).

Footwear fit, important to foot health, is the marriage of form and function of both the foot and the shoe. Ideally, changes in foot morphology should be monitored in different population groups in order to provide useful information for last makers and shoe manufacturers. Many factors affect footwear fit, but for the purposes of this chapter, only the physical aspects of the concept of fit related to foot morphology are explored. These physical 3D aspects determine the design of lasts, which allow the closest match of fit to function.

22.5 TO MAKE A SHOE: THE LAST IS FIRST

Footwear is manufactured using specialized foot forms or "lasts," as shown in Figure 22.1. The origin of the word "last" is from an Anglo Saxon word "laest," meaning footprint or foot track (Rossi 2000). The last is the working surface on which the components that make up a shoe (such as the upper, the sole, and the heel) are shaped and attached to each other. The size and shape of the last determines the exact size, shape, and fit of the footwear produced on it. It follows then that there are as many different lasts as there are sizes and shapes of shoes.

Until the 1960s in Europe and the United States, last model makers shaped lasts by hand from wood. Today, plastic has largely replaced wood in commercial last making and shoe manufacture, since plastic is more stable through temperature and humidity changes (Rossi and Tennant 1984). Measurements on a plastic last will not change due to warping or swelling. Curiously, some last makers still refer to the "adding of wood" to describe the addition of volume to a last.

22.5.1 Measurement for Last Making

In traditional last making, lasts are interpreted by a model maker from sets of measurements, according to a standard (e.g., the British or UK standard, Continental or Paris Point, American, Japanese) as requested by a particular manufacturer. Twenty years ago, custom requirements could necessitate some 15–30 manual measurements of the foot to create a custom last (Rossi 1980; Miller and Redwood 1989). Today, laser scanning and camera technology allow 3D scans of the foot to be captured, transformed by computer-assisted design (CAD) software, and output to 3D print or milling machines. With the advent of 3D technology, it is now possible to digitally create an individual last based on the foot scan of a particular individual, or assess whether a last is unsuitable for a population, as shown in Figure 22.2.

The measurements to make a last are calculated from foot measurements, to which a number of additional "allowances" are added or differences made, as shown in Figure 22.3. The most basic of these measurements are foot length, tread width, and tread girth, also known as ball girth or circumference. An example of an allowance is "toe recede," the area on the last that equates to the toe end of the shoe, and which extends beyond where the physical tips of the toes would end.

22.5.2 Different Lasts for Different Styles

Last makers begin a last for a new style by making a model last for a single size. A model last for a woman's shoe in South Africa is generally made to what is referred to as a "women's UK size 4," corresponding to a foot length of 234 mm and a tread width of 84 mm. Styling that deviates from the

FIGURE 22.1 Last and lasted shoe.

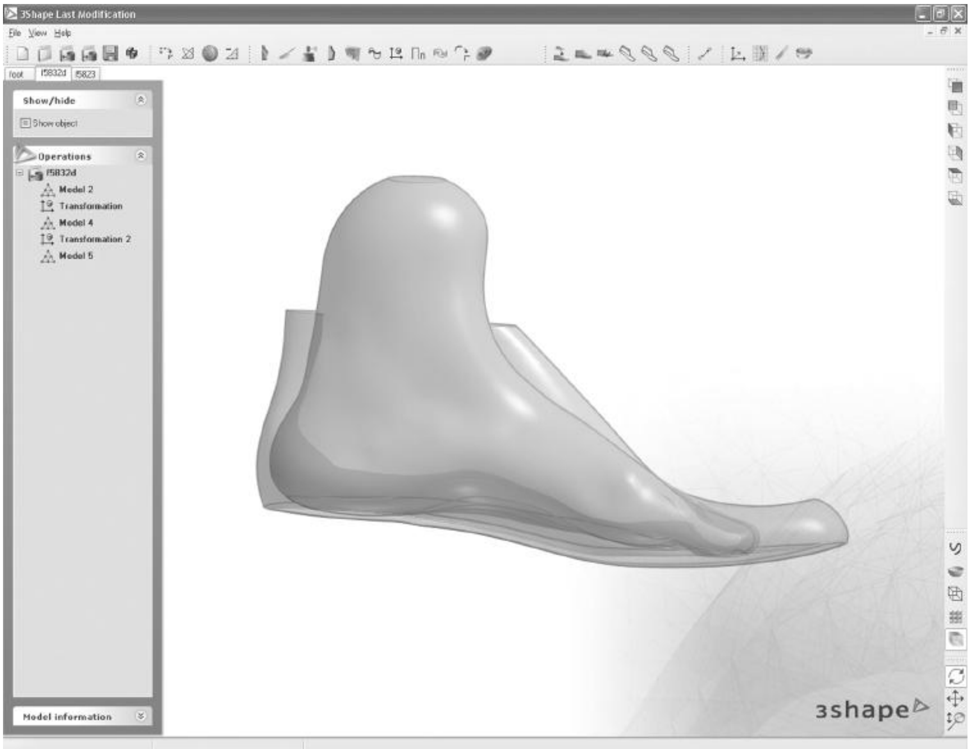


FIGURE 22.2 3D Assessment of fit between last and foot.

natural form of the foot (e.g., a pointed toe shape) must be embodied in the form of the last so that it will translate onto the shoe; thus different lasts are used for different styles (Miller and Redwood 1989).

Particularly in women's footwear, the demand for variation in fashion means that there is a last for every single different construction style and heel height. Since there are so many shoe styles, requiring corresponding lasts, it would be impractical without 3D analysis to compare all lasts for women with the population's feet. Fashion is constantly evolving, reflecting contemporary attitudes, trends, or lifestyles. However, shoe styles happen to be based on a few basic style forms, usually a variation of a basic style family.

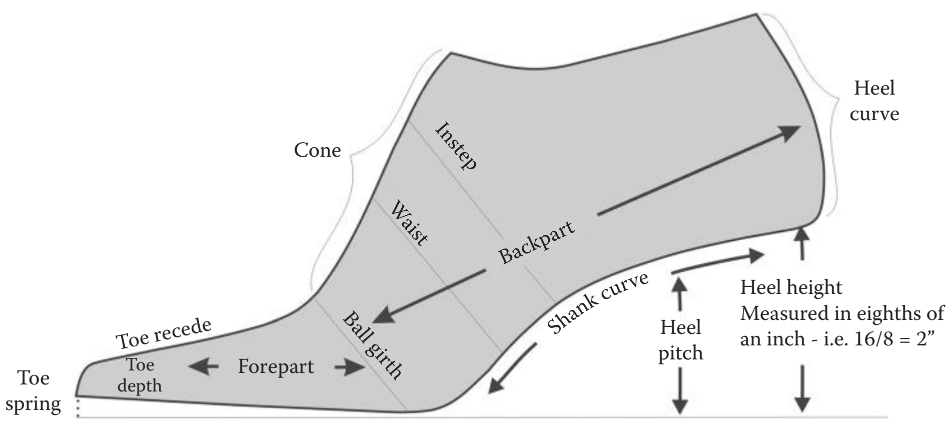


FIGURE 22.3 Measurement parameters on a last. (After Adrian, K.C., *American Last Making*, Brown Shoe Company, St. Louis, MI, 1991.)

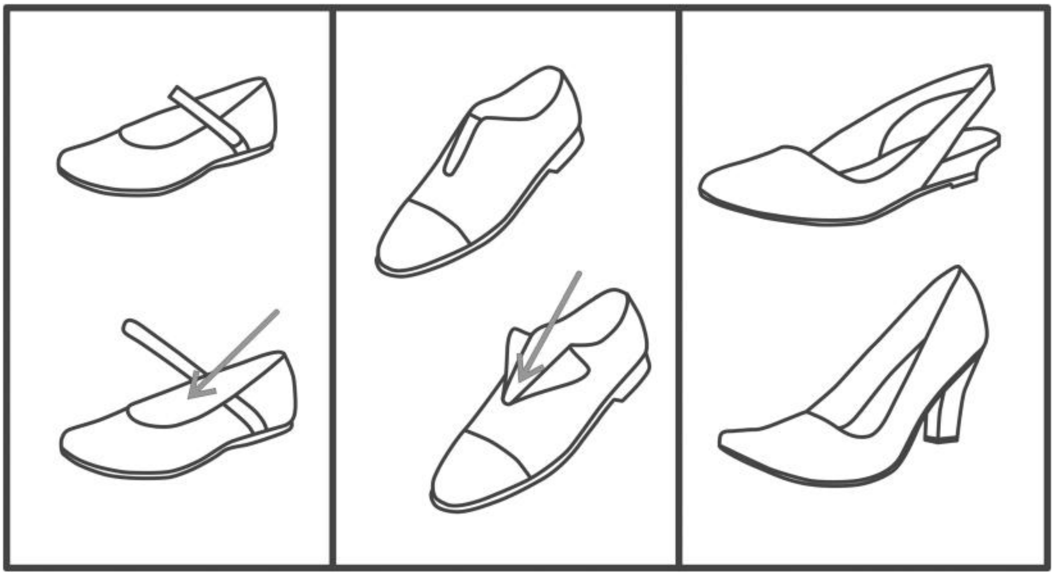


FIGURE 22.4 Examples of open tab, closed tab, and slip on styles. Column A: open tab footwear has ample opening to admit the foot in the instep area. Column B: closed tab footwear has a limited opening that is not as wide as open tab footwear. Column C: slip on footwear admits the foot easily and is held in place by "clip" and friction. (After Riches, K., *Footwear Product Knowledge*, Ken Riches Footwear Consultants, Port Elizabeth, 1980a.)

Differing classifications exist as to what constitutes a basic style. Riches (1980a) maintains that there are three shoe styles: open tab, closed tab, and slip on (Figure 22.4). Both open and closed tab styles have some kind of fastening so that the foot can enter the shoe easily and by which the shoe stays firmly on the foot. Slip on footwear has no special fastening to keep the shoe on the foot. By contrast, Rossi (1985) maintains that there are seven shoe styles; boot, clog, oxford, moccasin, mule, pump, and sandal (Figure 22.5). Menz and Sherrington (2000) added a further eight general shoe styles but omitted the mule style to form a new grouping of 14 style options. Table 22.1 shows the overlapping of these three methods of classification, mainly on the basis of their function. Each of these classification systems has their merits. The classification by Riches (1980a) is related to footwear manufacture considerations, while the classification by Rossi (1985) appeals to foot health specialists such as podiatrists, who are concerned with foot function. The classification by Menz

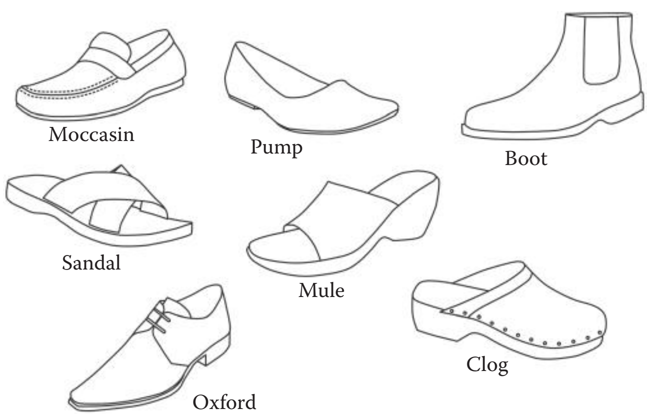


FIGURE 22.5 The seven basic shoe styles. (After Rossi, W.A., *Journal of the American Podiatry Association*, 75, 169, 1985.)

TABLE 22.1
Overlapping Shoe Style Classifications

Riches (1980a)	Rossi (1985)	Menz and Sherrington (2000)
Slip on	Mule or clog	Mule
Slip on	Mule or clog variant	Backless slipper
Slip on	Mule or clog variant	Thong
Slip on	Mule or clog variant	Slipper
Slip on	Pump	Court shoe
Slip on	Moccasin	Moccasin
Slip on/open/closed tab	Pump variant	High heel
Slip on/open/closed tab	Sandal	Sandal
Closed tab	Oxford	Oxford
Open/closed tab	Oxford variant	Walking shoe
Open/closed tab	Oxford variant	Athletic shoe
Open tab	Oxford variant	Surgical/bespoke footwear
Open/closed tab	Boot	Boot
Open/closed tab/slip on	Boot variant	Ugg boot

and Sherrington (2000) extrapolates the Rossi classification using commonly known names in order to make consumer surveys easier.

22.5.3 Last Curvatures: Art or Science?

In traditional last making, the model maker uses artistic skill to form the curvatures of the last, for which, generally, only six measurements are taken, using a combination of a last stick and last tape (Riches 1980b; Cavanagh 1980). Depending on the sculptural skill and experience of the individual last maker, the outcome can be highly variable. Dimensional accuracy is important when considering fit in any section of the shoe. For example, heel curves in a last should be matched to the heel curve shapes of the feet in the population for whom the shoe is intended (Lucock 1972). Advances in computer technology make alternative, high speed, and digitally accurate means of 3D measurement available to reproduce these curves. The combination of these curves directly affects the fit of the shoe.

For example, it is theoretically possible to have two individuals whose foot shapes are different, yet share identical forefoot circumference. As can be seen from Figure 22.6, each shape might have

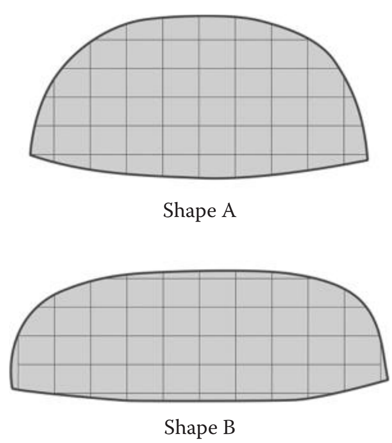


FIGURE 22.6 Identical ball girths on different shape lasts. (After Rossi, W.A. and Tennant, R., *Professional Shoe Fitting*, National Shoe Retailers Association, New York, 1984.)

the same girth circumference but have a different width. This results in a different forefoot shape in which the different bottom or tread will affect foot function. Similarly, ball or joint volume shape differences exist between different foot types, as seen in Figures 22.7 and 22.8. These foot types could share certain common measurements but require a different last. Often, when the forepart width of a fashion shoe is narrowed in a cosmetic attempt to make the shod foot look more slender,

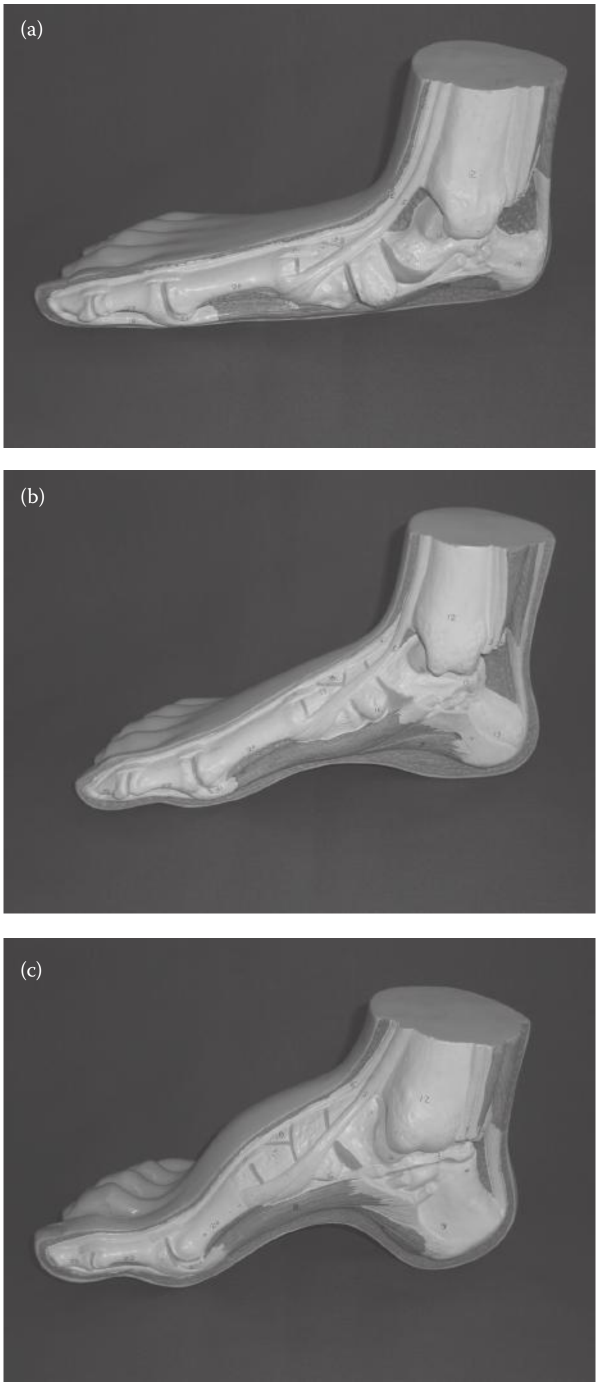


FIGURE 22.7 A pes planus, "normal" or regular, and a pes cavus foot.

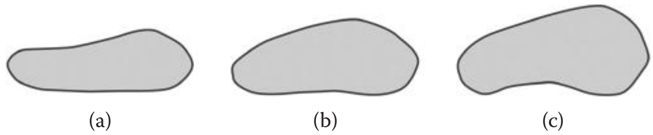


FIGURE 22.8 Coronal plane forefoot shapes of three different foot types. (a) pes planus; (b) normal or regular; (c) pes cavus.

crowding of internal foot structures such as metatarsal heads, blood vessels, and nerves occurs. Because of the differences in elevation and posture of the forefoot in these examples, it can be understood that the height and shape dimensions in the region of the metatarsophalangeal joints (ball of the foot) forefoot region, will also differ, as shown in Figure 22.8. Last shapes that are created with different curve combinations will thus feel and fit differently on the foot.

22.5.4 Last Sizing and Grading

The English (UK) size system is believed to have originated in 1324 when King Edward II decreed that three average sized barley corns, placed end to end, would equal one inch (Cavanagh, 1980). For a human foot, thirteen inches or thirty-nine barley corns long, each size smaller than "size thirteen" was one less barley corn. This system continues today in the present sizing system in which the length unit between English sizes is one-third of an inch. Size twelve is twelve and two-third inches long. Lasts are "graded" in length increments of one-third of an inch or 8.46 mm (Rossi and Tennant 1984; Turner 2006). The system is not linear; size zero starts at exactly four inches for a child's shoe. Children's shoe sizes progress through thirteen sizes until they end at eight and one-third inches, at which point both men's and ladies' sizes commence. Thus, size two for adults is nine inches long, as seen in Figure 22.9 (Rossi and Tennant 1984).

In the North American sizing system, the length difference between sizes is the same (one-third of an inch) but size zero starts at three and eleven-twelfths inches instead of four inches. UK shoes on the American population therefore, fit slightly looser (Rossi and Tennant 1984; Turner 2006). Figure 22.10 illustrates that while men and women's sizes in the UK system are the same length, the American system for women's sizes does not match that of men. Since the size increment in both the British and American systems is 8.46 mm, this has necessitated "half sizes" to accommodate those feet that fit neither the full size above and below.

A third system called Continental sizes (sometimes referred to as Paris Points) consists of one continuous range based on the metric system. Size zero Continental starts at 0 cm and the difference between sizes is two-thirds of a centimeter or 6.66 mm (Cavanagh 1980). No "half sizes" are made since the size increment is smaller and enables a better fit.

It is important to note that the British, American, and Continental systems derive size from a "stick length" measurement of the last, not of the actual foot, as in the Japanese system. Japan has its own sizing system, sometimes referred to as the metric system (Kouchi and Mochimaru 2008). In the Japanese shoe size system, shoe size is determined by length and ball girth, and the shoe size indicates the size of the foot that fits to the shoe, not the size of the shoe itself. Human foot length and foot circumference correspond, respectively, to the length and ball girth of the shoe. Length is indicated in centimeters. Since foot circumference could be quite different even when the foot length is the same, there are shoes of the same length but with different ball girths. A woman's shoe with average circumference for the Japanese population is called "E," and becomes EE, EEE, EEEE, with increasing ball girth, while "E" becomes D, C, B, or A with decreasing ball girth. To cope with variations in foot size, Japanese shoe length sizes change by 5 mm, with ball girths changing by 3 mm. In the Japan Industrial Standard (JIS) of shoes, sizes range from 20A to 30G for adult males, from 19.5A to 27EEEE for adult females, and from 10.5B to 26G for children's shoes.

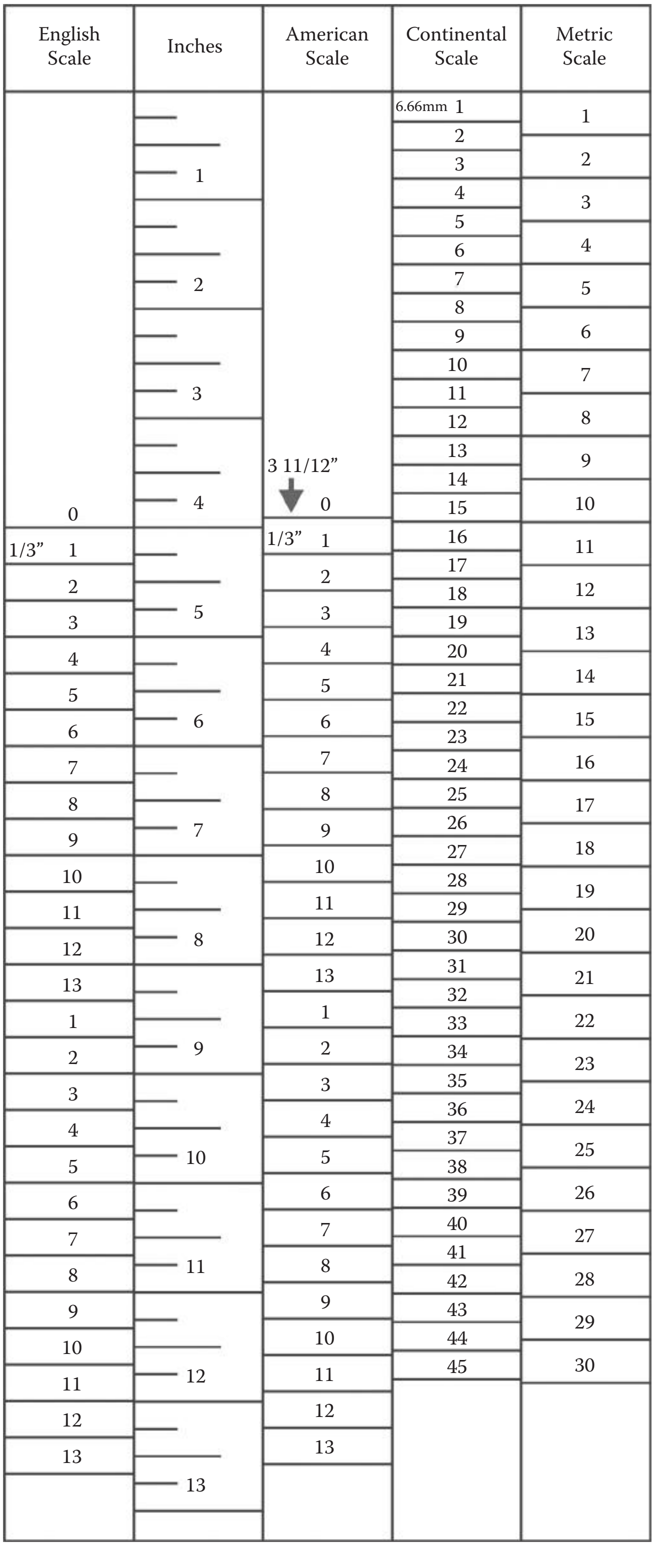


FIGURE 22.9 International scale comparisons. (After Adrian, K.C., *American Last Making*, Brown Shoe Company, St. Louis, MI, 1991.)

FOOTWEAR SIZE CONVERSION TABLE					
Woman and Girls			Men and Boys		
EU	UK	USA	EU	UK	USA
31	12½	1	32.5	13½	1
32	13	1½	33	1	1½
32.5	13½	2	34	1½	2
33	1	2½	34.5	2	2½
34	1½	3	35	2½	3
34.5	2	3½	36	3	3½
35	2½	4	36.5	3½	4
36	3	4½	37	4	4½
36.5	3½	5	38	4½	5
37	4	5½	38.5	5	5½
37.5	4½	6	39	5½	6
38	5	6½	39.5	6	6½
39	5½	7	40	6½	7
39.5	6	7½	41	7	7½
40	6½	8	41.5	7½	8
40.5	7	8½	42	8	8½
41	7½	9	43	8½	9
42	8	9½	43.5	9	9½
42.5	8½	10	44	9½	10
43	9	10½	44.5	10	10½
44	9½	11	45	10½	11
44.5	10	11½	46	11	11½
45	10½	12	46.5	11½	12
45.5	11	12½	47	12	12½
46	11½	13	48	12½	13

FIGURE 22.10 Footwear size scale conversion. (After Adrian, K.C., *American Last Making*, Brown Shoe Company, St. Louis, MI, 1991.)

Attempts to harmonize the various systems have been made by creating a single metric world system, called Mondopoint 5 mm and Mondopoint 7.5 mm, in which foot length size increments are 5 or 7.5 mm, respectively (Riches 1980b). Mondopoint implementation did not succeed, in part due to the economic impact of replacing existing lasts for all manufacturers. In 2007, Continental sizing was proposed by the International Standards Organization's Technical Committee for Global Sizing and Marking as the sizing standard that should be reflected side-by-side next to any country's existing sizing for ease of reference by consumers in a global market.

22.6 THE FOOT: GENERAL ANATOMY FOR ANTHROPOMETRY

All measurements for last sizing and grading systems start with the dimensions of the foot, which is determined by the anatomy of the foot. The skeleton of the human foot is a complex asymmetrical arrangement of twenty-six bones that can be divided into three groups, namely, the tarsus, metatarsus, and the phalanges, as shown in Figure 22.11. Differences in the size and shape of the underlying bones, overlaid by the myriad of muscles, ligaments, tendons, cartilage, nerves, blood vessels, and skin, result in individual variations in morphology.

Certain anatomical structures beneath the skin determine the external shape and size of the foot and ankle. One approach in clinical examination of the foot is to identify palpable external bony landmarks, as these indicate the position and extent of underlying bone structures. Palpation will also reveal the shape and position of muscles, joint, tendons, and ligaments (Lumley 1990) as found attached to underlying bone (Figure 22.12). In turn, all of the palpable and underlying anatomy is covered in skin, which defines the anthropometric shape and dimensions of the foot and ankle (Figure 22.13).

Many references exist to assist in the location of bony landmarks, as is typically undertaken in a measurement study. For example, the lower part of the fibula is palpable about 15 cm above the

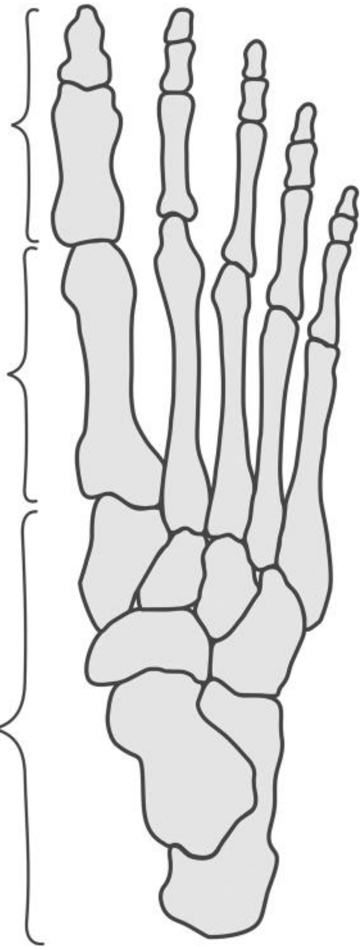


FIGURE 22.11 Bones of the foot.

lateral malleolus, and extends downward, ending up lower than the level of the medial malleolus. To detect the groove for the peroneal tendons, one would press firmly with a fingertip upwards and forwards from behind the most distal part of the lateral malleolus (McKears and Owen 1979). With the advent of 3D, external bony landmarks can be recorded at the same time as recording the 3D image. Figure 22.14 illustrates a 3D foot image in which bony landmarks of the foot have been recorded with a stylus marker after palpation for positioning.

22.6.1 Anomalous Variations in Morphology

22.6.1.1 Loss of Muscle Function

Certain neurological conditions, such as polyneuritis and cerebral palsy, affect muscular function in the lower limb and the foot. Impaired neural function leads to muscle atrophy. The resultant changes in muscle bulk impact the typical morphology of the foot (Rendall, Thomson, and Boyd 1997).

22.6.1.2 Edema

Pathologies such as systemic illness, infections, vascular impairment, trauma, arthritis, toxins, medication interactions, or metabolic illnesses such as diabetes mellitus or hypothyroidism can lead to edema or swelling of the foot and ankle, thereby altering the foot's typical morphology (Beers and Berkow 1999). (See also 22.6.2.3 for non-pathological causes of swollen feet.)

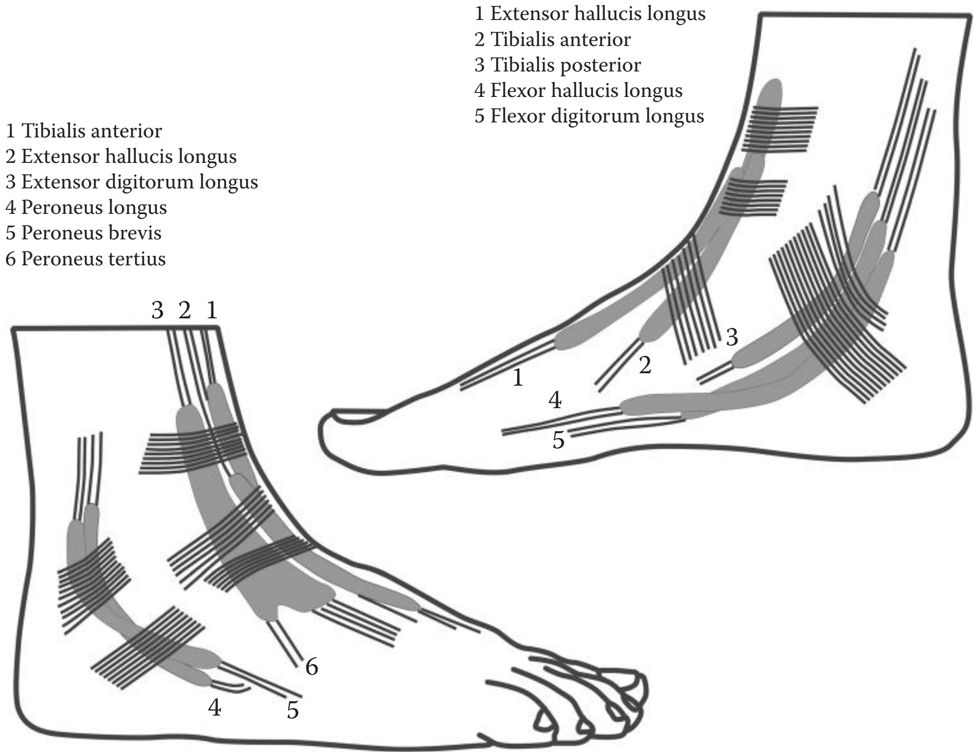


FIGURE 22.12 Position of retinaculae and synovial sheaths of the foot. (After Backhouse, K.M. and Hutchings, R.T., *A Colour Atlas of Surface Anatomy*, Wolfe Medical Publications, London, 1989.)

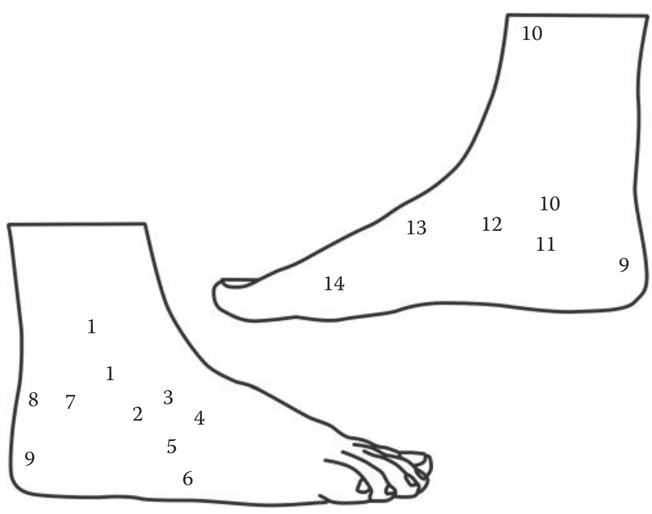


FIGURE 22.13 Foot surface anatomy. Key: 1. Fibula to lateral malleolus. 2. Peroneal tubercle. 3. Talus (distal projection). 4. Extensor digitorum brevis muscle. 5. Calcaneal tubercle. 6. Base of the fifth metatarsal. 7. Peroneal tendons. 8. Achilles tendon. 9. Calcaneus (proximal projection). 10. Tibia to medial malleolus. 11. Sustentaculum tali. 12. Navicular tubercle. 13. Base of first metatarsal. 14. Head of first metatarsal.

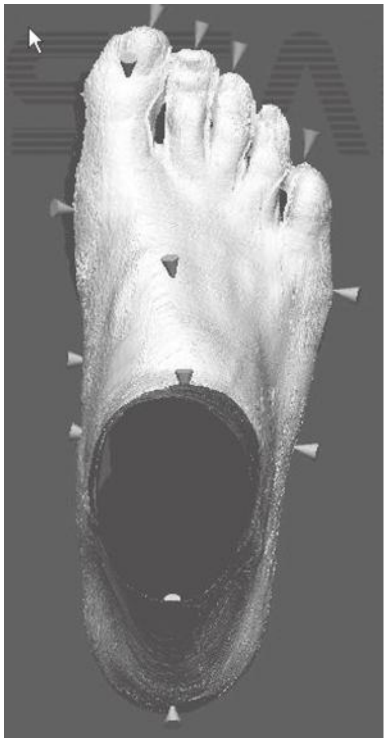


FIGURE 22.14 3D foot image incorporating bony landmarks of the foot.

22.6.1.3 Trauma

Foot anomalies, pathologies, and trauma can change the conventional morphology of the foot (Hughes 1995). Examples of such conditions include hallux valgus (commonly known as bunions), deformities of the digits (such as hammer toes), loss of muscle function, and edema.

22.6.2 Typical Variations in Morphology

Many different variations of foot morphology occur naturally. Some researchers have developed classification systems based on variations in the medial longitudinal arch height, such as pes cavus or pes planus; others on foot function related to planar movements such as supination and pronation (Rendall, Thomson, and Boyd 1997; Root, Orien, and Weed 1977). Still others have classified the feet according to forefoot shape, such as square foot, Greek foot, or Egyptian foot, determined by differing metatarsal and phalangeal (toe) lengths (Viladot 1973). In the shoe industry, feet may be termed long-narrow, short-wide, inflared, outflared, fleshy, or bony (Riches 1980b). These terms are echoed in descriptions used in traditional last manufacture.

While most studies investigated the variation in volume or foot length, only recently have studies investigated changes in foot shape and their interaction with footwear due to such changes (Kouchi 1996; Houston 2002; Luximon, Goonetilleke, and Tsui 2003; Kurz and Stergiou 2004; Krauss et al. 2005).

Beyond structural variations, there are also variations in the foot due to age, gender, and other factors.

22.6.2.1 Age

Although Anderson, Blais, and Green (1956) state that feet stop growing in length in 75% of girls by age 14 even though they may increase in stature, some assert that internal growth in the foot ends between ages 20 and 21 in females (Tachdjian 1990). Lewis, Lavy, and Harrison (2002) highlight the fact that the Greulich and Pyle Atlas, conventionally used to assess skeletal maturity in studies in the developed world, is not necessarily relevant to sub-Saharan populations. This is possibly due to poor nutrition and chronic diseases delaying the onset of maturity. Anderson, Blais, and Green (1956) also do not address probable change in foot shape, volume, or proportion after age 14 in females. In fact, Rai, Bansal, and Prakash (1978) confirmed earlier observations made by Hill (1958) that foot girths continue to increase even after foot length growth has ceased.

As a consequence of general loss of tone, decreasing collagen levels and other effects of aging, female foot size continues to alter with age (Frey et al. 1993; McGlamry 1978; Schuster 1978). Foot spread can contribute to increased foot width with aging, while loss of plantar fibro-fatty pad thickness and elasticity can increase with age and contribute to the altered shape and function of the foot (Özdemir et al. 2004).

22.6.2.2 Growth Environment

While the deforming and growth-inhibiting effects of ancient practices such as foot binding have been documented (Jackson 1990), other environmental factors can affect the size and shape of the foot, sometimes within the same day. These include heat and moisture.

22.6.2.3 Temperature and Fluid Balance

Foot shape can be affected by heat, humidity or moisture and friction within the shoe. Foot volume can differ by 5% at the end of a day compared to early morning, due to thermal conditions (Rossi and Tennant 1984). Increased ambient temperature and fluid imbalances in the body can result in an accumulation of fluid in the tissues (Hargens 1981), often visible as swollen feet.

22.6.2.4 Load

The weight-bearing foot differs from the static or resting foot in shape, size, and proportions (Rossi and Tennant 1984). "Weight bearing" refers to the foot on standing erect, not walking or running. These altered dimensions, such as increased tread width and lowered arch height, differ between individuals according to the flexibility and structural mechanics of the foot (Lord and Pratt 1999).

Tests have shown that the foot on weight bearing elongates, not only distally but proximally as well, where there is a certain amount of rearward thrust of the heel (Rys and Konz 1994). On weight bearing, the foot widens across both the ball and the heel, and there is more spread of volume at the waist and instep. After four hours of standing, forefoot maximum width can increase by 3% due to vascular "pooling" (Rys and Konz 1994).

22.6.2.5 Activity

Understandably, there are morphological variations of the foot during movements such as walking, running, dancing, and jumping. During such activity, the foot moves through multiple planes (Seibel 1988; Root, Orien, and Weed 1977) and assumes different combinations of size, shape, and proportions, due to the differing bulk of the underlying anatomical structures, as different muscles contract and relax (see Section 22.5).

22.6.2.6 Asymmetry

In 1982, the National Prescription Footwear Association in the United States, in collaboration with podiatrists and retailers, performed measurement of 6800 pairs of adult men and women's feet in 23 cities. Measurements taken were overall foot length, ball width, heel-to-ball length, and heel width of both the left and the right foot. Measurements were recorded both with the participants seated and then again on weight bearing. Not a single perfectly matched pair of feet was found (Rossi 1983).

22.6.2.7 Sexual Dimorphism

Apart from variations due to body type, variations in foot shape and size have been ascribed to gender, age, and ethnicity (Cheskin 1987; Kouchi 1989). According to some American studies, the mean female foot length is approximately 91% of the mean male foot length (Rys and Konz 1994; Konz and Subramanian 1989).

Gender differences (sexual dimorphism) in adult lower limb structure and foot shape show that the female foot is not a scaled-down version of a male foot. Different shape characteristics are found, for example, at the medial arch, the lateral side of the foot, the first toe, and the ball of the foot (Wunderlich and Cavanagh 2001). Sexual dimorphism in the skeletal foot is well documented (Kidd and Oxnard 1997; Kidd 1995; Zipfel, Kidd, and Berger 2003; Ferrari, Hopkinson, and Linney 2004; Zipfel 2004; Tobias 2005). These "dimorphisms" are subtle, yet verifiable and manifest in "external" morphology (Zipfel 2004; Krauss et al. 2005).

22.6.2.8 Pregnancy

Increased production of estrogen and the increased level of aldosterone are responsible for the sodium-retaining effect that results in generalized and lower limb edema in pregnancy (Bell, Davidson, and Scarborough 1968). Also to be taken into consideration are the physical factors such as increased pressure of the growing uterus against blood vessels (supplying the lower limbs) and lymphatics (draining the lower limbs) in the lower abdomen that can lead to hypertension (Beers and Berkow 1999).

22.6.2.9 Population Group

Studies have shown not only gender differences, but also morphological variations between human sub-group phenotypes and populations (Patriquin, Loth, and Steyn 2003). Evidence of population variations in foot morphology exists in a variety of sources. Archeological findings, for example, in the British Isles have shown differences between Saxon and pre-Saxon foot bones that translated into general foot morphology differences between modern Scots-Irish females and modern English females at that time (Jackson 1996).

Several studies indicate ethnic and/or sub-group differences in foot morphology, and support the movement toward unique shoe lasts for each population group where variation justifies it (Hawes et al. 1994; Benard and Stephens 1979; Anil et al. 1997; Baba 1975; Parham, Gordon, and Bensel 1992).

In the study of genetics, combinations of DNA polymorphisms are known as haplotypes (Hitzeroth 1986). Haplotypes and polymorphisms have been found to distinguish, for example, the Khoisan people from other African peoples (Steinberg et al. 1975). A radiographic study of the calcaneal angle found significant ($p < 0001$) differences between Ugandan and Nigerian women (Igbigbi and Mutesasira 2003). Morphometric studies of the foot bones have shown significant variation in bone shape, both within groups (sexual dimorphism) and between groups (e.g., Ferrari, Hopkinson, and Linney 2004; Kidd 1995; Zipfel 2004; Zipfel and Kidd 2008). Clearly, differences between males and females have arguably already been considered by the footwear industry, but differences between groups have received much less attention.

22.6.3 Relevance of Anatomical Variation to Three-Dimensional Footwear Design

The great extent of known and expected variations in foot morphology would seem to undermine the possibility of the footwear industry ever making a shoe that would fit even one group of individuals. Yet, modern ergonomic and 3D anthropometric studies have been successful in forming groups of statistically verifiable anatomical characteristics so that "clustered" body and foot types are defined. It is important that the process of gathering 3D foot morphology databases be instituted for each country, so that accurate 3D foot measurements can reduce the risk of poor fit, reduce litigation costs, and increase the chance of success of the footwear in the market.

Anthropometric 3D measurement studies should be stratified from a representative cross-section of the population, so that as many anatomical variations as possible are represented and recorded for principal component or "cluster type" studies. Analysis of a country's data in this way may reveal a foot type previously not accommodated by the shoe industry (Thompson 2006).

22.7 NON-PHYSICAL FACTORS AFFECTING FIT

Physical dimensions and variations are not the only considerations when it comes to footwear fit. More than three decades ago, the Battelle study as described by Rossi (1988) described thirty-seven factors affecting footwear fit (Figure 22.15). Among these were mechanical factors such as anatomical or physical measurements, and sensory factors such as materials and fabrics used. There are

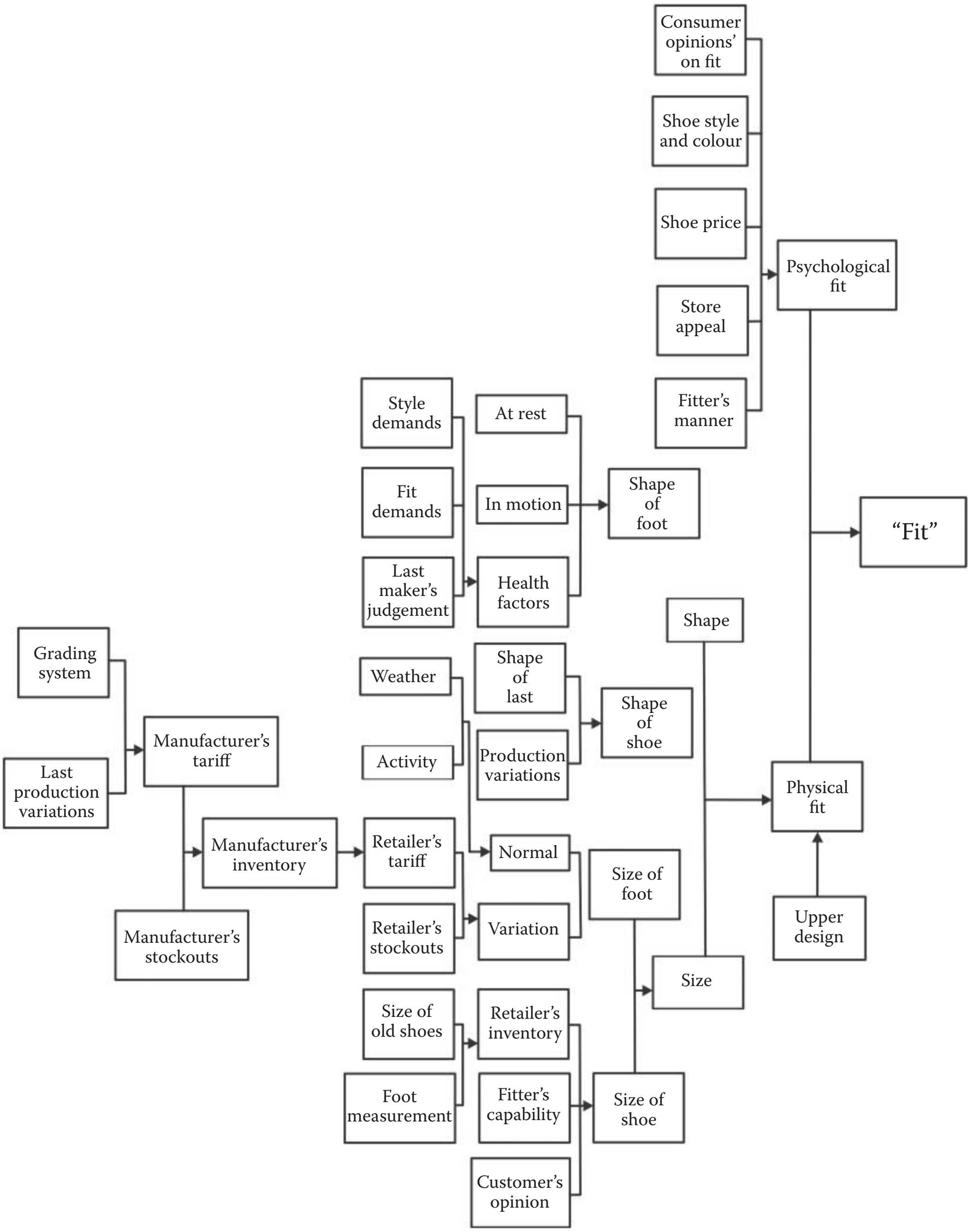


FIGURE 22.15 Factors affecting fit according to the Battelle study. (After Rossi, W.A., *Journal of Testing and Evaluation,* 16, 393, 1988.)

also many psychological and sociological factors such as price, peer pressure, and fashion trends that exert enormous influence on the selection of footwear. Fashion has been responsible for such features as stiletto heels, platform soles, and backless shoes. These features are not generally compatible with proper fit, nor do they facilitate natural foot function.

22.7.1 Perception of Fit

Many years of habitual foot deformation can contribute to a preference for tightness (Lord and Pratt 1999). Similarly, the experience that a smaller shoe can stretch may mislead some consumers to the conclusion that, "since it's going to stretch," one should buy it tight to start with (Rossi 1988). Other reasons for accepting a shoe that is too tight may be due to a desire to make the feet appear smaller. Individual preferences for "tightness" can, therefore, influence a wearer's subjective perception of fit.

The implication of this aspect is that it may be necessary to educate consumers to accept what they would initially perceive as a slightly looser fit than what they are accustomed to (Lord and Pratt 1999).

22.8 HUMAN FACTORS IN FOOTWEAR DESIGN

According to Rossi (1988, 393), a shoe fits "when the dimensional profile and sections of the shoe correspond to the dimensional profile and sections of the foot." As discussed in Section 22.3, foot pathology due to pressure and friction can result from a mismatch between the foot dimensions and those of the shoe. Variations in feet will affect their match with footwear.

22.8.1 Why the Last Cannot be Identical to the Foot

Lasts need to have certain differences to enable them to be a tool for the shoemaking process (Miller and Redwood 1989; Lucock 1972). The last does not attempt to replicate individual toe contours nor toe web spaces, since footwear is shaped to the toe area of the last as a working surface. In addition to filling in the contoured surface shape corresponding to the toes, lasts have a feather edge or line. This is a well-defined edge between the top of the last and the bottom of the last, so that the sole of the shoe can be attached to the upper.

Differences between a foot and a last include a length allowance, fashion allowance, extra depth over toes, extra or less girth allowance over the joint girth, toe spring, and last pitch. Last pitch is also known as heel pitch or heel height (Riches 1980b; Miller and Redwood 1989). According to Lucock (1972), these are adjustments intended to allow for all the movements of the foot within the footwear for which it is designed. These adjustments have evolved empirically. For example, toe spring in a finished shoe should not exceed 7 mm, or the wearer will eventually experience shortening of the extensor tendons, with resultant muscle imbalance in the foot.

Certain styles of shoes need further allowances in order to facilitate the manufacture of the shoe, or to enhance some property of the shoe in wearing. Examples of these allowances include wider heel seats for sandals; more scooped side swells for pumps in order to increase top line "clip" (the grip exerted on the sides of the foot by the shaping of the shoe); shorter overall length for open-toed sandals and moccasins; and wider front cones for some styles such as boots.

Since the last is most responsible for the fit, shape, style, and size of the footwear produced on it (Miller and Redwood 1989), it can be understood that the measurements for a last and its 3D design are linked to foot health in a shoe-wearing population.

22.8.2 Importance of Toe Function

In the gait cycle, all five toes may be in contact with the ground for longer than the heel and the base of the fifth metatarsal. Toe contact, in fact, occupies nearly three-quarters of the gait cycle (Hughes, Clark, and Klenerman 1990).

The metatarsal area thus not only carries body weight, but the toes also contribute a weight-bearing area (Mann and Hagy 1979). Peak pressures under the toes, when the intrinsic forefoot muscles are able to contract together with the long flexors, are similar to peak pressures found under the metatarsal heads (Hughes, Clark, and Klenerman 1990; Bojsen-Møller and Lamoreux 1979).

According to Stamm (1964), the primary function of toes is to press firmly against the ground with their pads to take weight from the metatarsal heads. As a result, the toes improve grip and prevent backwards skid. The outer and inner toes work to exert the precise and constantly changing amounts of pressure required to maintain balance when the heel is raised.

It is the combined contraction of three groups of muscles, namely, the long flexors, interossei, and lumbricals that brings about this pressor toe action. If contraction takes place in the long flexors alone, this would only flex the interphalangeal joints. This would result in just the tips of the nails touching the ground, as the interphalangeal joints are flexed (Figure 22.16b). It is the action of the interossei and lumbrical muscles that maintains the interphalangeal joints in extension, and this action then transfers the flexor action of the long flexors to the metatarsophalangeal joints (Figure 22.16c).

At the same time, it is the action of the interossei and lumbrical muscles, combined with that of the adductor hallucis, that braces the transverse arch of the foot (Figure 22.16c). It is entirely

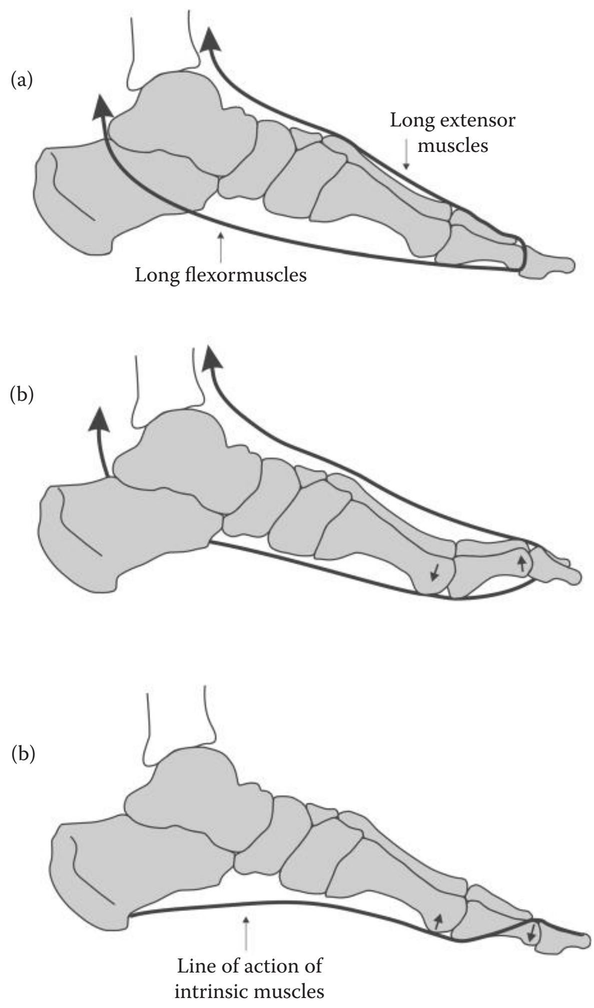


FIGURE 22.16 Action of muscles on toes. (After Stamm T.T., *A Guide to Orthopaedics*, Blackwell Scientific, Oxford, 1964.)

understandable that poor interossei and lumbrical action also then contribute, via medial column collapse, to the formation of digital and hallux valgus (bunion) deformity (Dawber, Bristow, and Mooney 1996; De Berker et al. 2002).

Figure 22.16 also shows that when the interossei and lumbrical muscles are weak or paralyzed, unopposed action of the long flexors will cause the progressive deformity of clawed toes. The fact that sufficient room for effective toe action is considered essential for maintaining integrity and painless function of the forefoot is endorsed by Arlen (1984).

At least one study of ethnic differences in forefoot shape has stated that greater length in front of the 5th digit is not provided in a typical shoe made for a Caucasoid population (Hawes et al. 1994). Section 22.8.4 explains how incorrect axial alignment of the last in which 6 degrees inflare or swing will reduce the space in the shoe required for the 4th and 5th digits.

On a last, the recede is the part that projects beyond the tip of the toes; it forms the rounded contour of the shoe front. Figure 22.17 illustrates that poorly designed recedes can encroach on toes, thereby impeding natural dorsiflexion of the toes as well as preventing length elongation during gait (Rossi and Tennant 1984).

Given that free toe dorsiflexion of all five toes is important (Stamm 1964; Hughes, Clark, and Klenerman 1990), there is a need to profile the varying "lengths" of the foot to the tips of all five toes. This will have relevance to the length allowances made on lasts.

Since free dorsiflexion of all toes is vital to natural gait, toes can only function efficiently when no pronatory or supinatory movement is placed on them (Stamm 1964; Mann and Hagy 1979), it must be remembered that propulsion of the foot takes place along a longitudinal axis, effectively dividing the foot into collaborating lateral and medial shock absorbing units.

22.8.3 Importance of the Longitudinal Axis of the Foot

Gait is most efficient in the absence of excessive pronation or excessive supination (Kerrigan et al. 1996; Phillips 2000; Ness et al. 2008).

To promote efficient, natural gait, podiatrists believe that footwear should not encourage excessive pronation nor excessive supination in the foot (Hughes 1995; Lord and Pratt 1997). Figure 22.18 shows the potential skeletal distortion caused by an inflared (supinatory) last, with visual comparison to the osteotomy and bone graft standard surgical procedure to correct metatarsus adductus, an axial alignment pathology of the foot.

In the pathology of metatarsus adductus, the metatarsals and digits are distorted away from the central longitudinal axis of the foot. The condition is graded according to degree of deformity

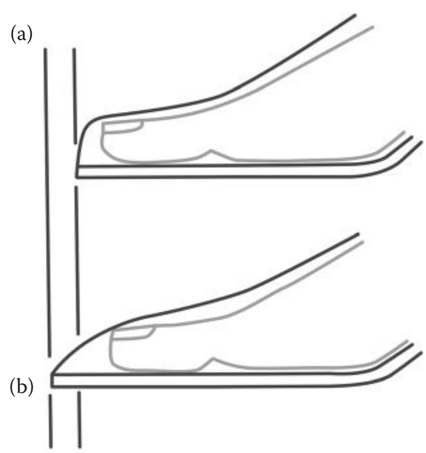


FIGURE 22.17 Impact of toe design on foot function.

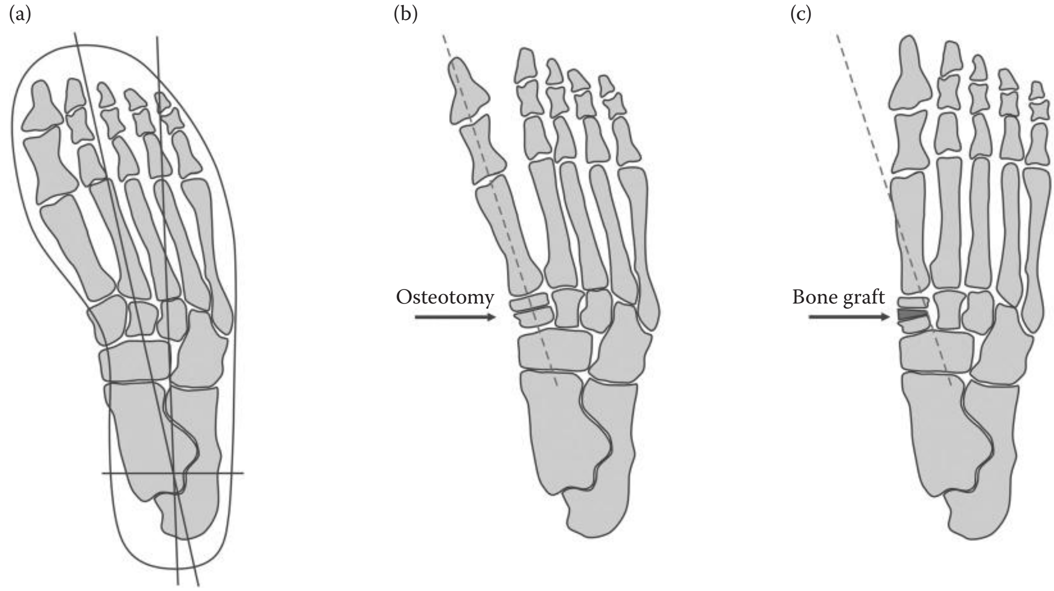


FIGURE 22.18 Torsion of foot in 6 degree axis footwear, with visual comparison to surgical correction of metatarsus adductus.

(Bleck 1983), particularly with respect to the position of the heel bisector, as shown in Figure 22.19. In a foot absent of metatarsus adductus, the bisection of the heel extended distally will bisect the forefoot and extend between the 2nd and 3rd metatarsophalageal joints to between the 2nd and 3rd toes. This is the clinically accepted normal longitudinal axis of the foot.

Any footwear, device, or shoe bed that holds the foot in a position different to that found in the foot's natural position can result in either bone and soft tissue modeling (if flexible) or stress pathology (if inflexible) or a combination of both, as well as altered foot function.

Figure 22.20 shows a foot bed shape in which the longitudinal axis equally bisects both the heel and the forefoot, as is found in feet with a normal longitudinal axis alignment, while Figure 22.21 illustrates how a last bottom pattern can be corrected from 6 degrees axial alignment to 2 degrees axial alignment.

Natural foot function is needed to form strong bones (Frost 1992). Better balance of foot muscle action leads to stronger and better developed natural feet (Jarrett, Manzi, and Green 1980; Bojsen-Møller and Lamoreux 1979; Burkett, Kohrt, and Buchbinder 1985). Thus, it is most important to examine the congruous relationship of the longitudinal axis of the foot to that of the last design.

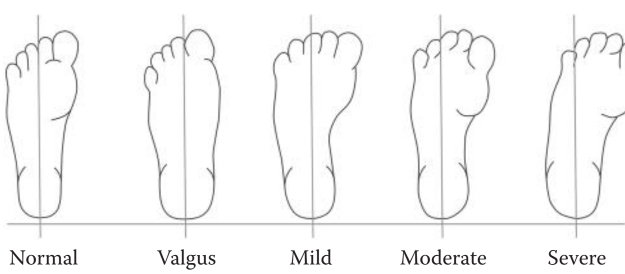


FIGURE 22.19 Classification of metatarsus adductus deformity. (After Bleck, E.E., *Journal of Paediatric Orthopaedics*, 3, 2, 1983.)

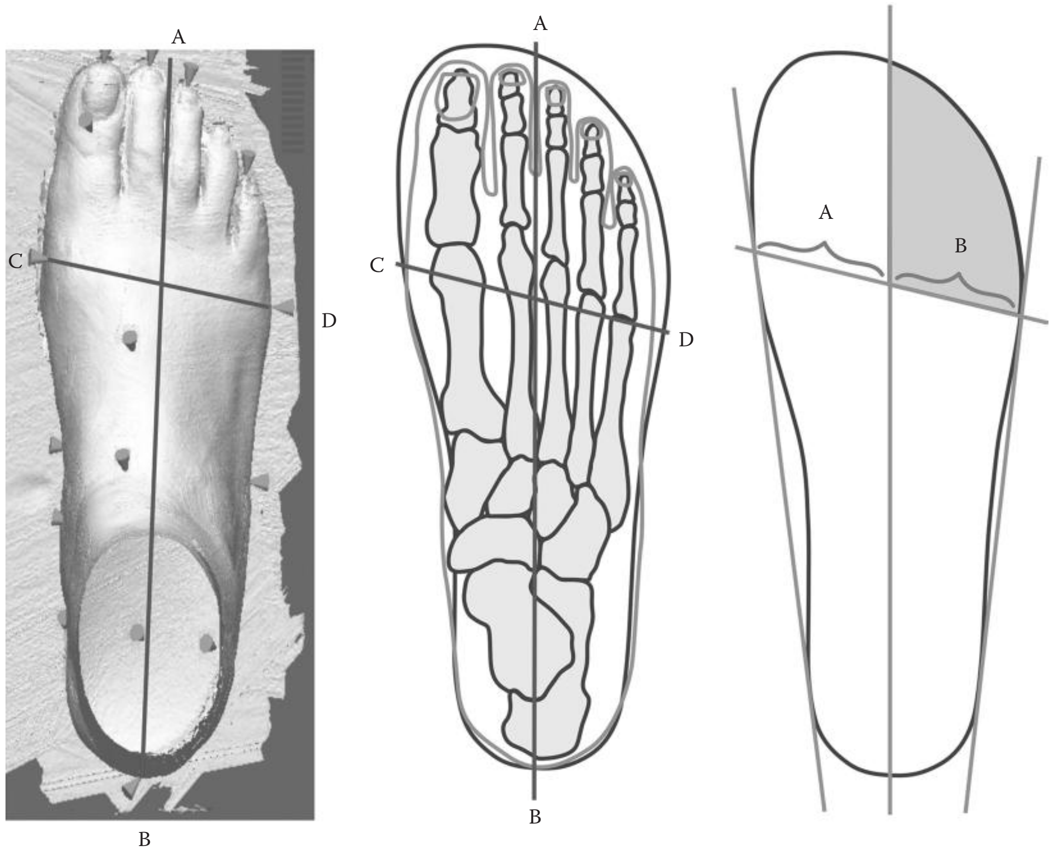


FIGURE 22.20 3D image analysis of normal axial alignment for last design.

22.8.4 Axial Alignment in Last Design

For over a century, the global shoe industry has used a last axis that is inflared or swung by 6 degrees in last bottom pattern design. No research evidence can be found to support this flare or swing in the axis. Some possible explanations include the fact that costs may reduce if one back part last pattern is used with mere variations of the forepart shape and vice versa; however, in the modern world of CAD/CAM design and high-speed milling, this is no justification for an anatomical anomaly in last design.

In analyzing 3D images of the anatomy of the foot, it is clear that footwear design on any last that incorporates 6 degrees of inflare or "swing" is only suitable for high-heeled shoes (in excess of 35 mm) since, in that posture, the calcaneus (heel) inverts, resulting in a supinated or inwardly curved foot form. Six degrees of swing or inflare is not suitable for plantigrade and/or low-heeled posture of the feet (0–35 mm); furthermore, such inflare or swing (when built into a shoe that holds the foot) will lead to torsion of the midfoot and compression of the outer lateral border—hence the overwhelmingly common prevalence of corns and calluses over the 4th and 5th digits.

Conventional last manufacture for both genders, irrespective of the heel height of the footwear, incorporates a 6 degree inflare or adducted "swing" of the forefoot, in relation to the longitudinal axis drawn from the bisection of the heel (Figure 22.21). Since the heel of the foot inverts (is supinated) just before toe off in gait (Seibel 1988), the adducted and supinated shape of the foot in this raised position was incorporated into heeled shoe design, giving rise to the supinated and adducted foot bed shape erroneously applied for the sake of economy to general last manufacture, irrespective of the elevation of the foot (Riches 2006).

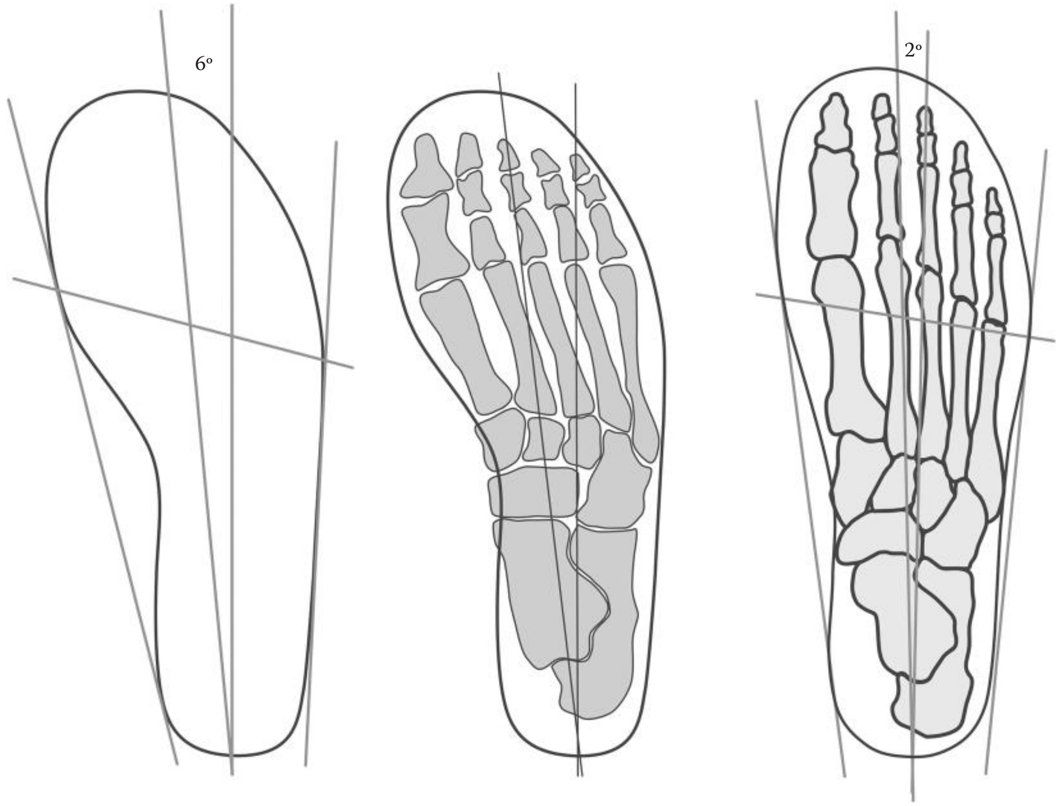


FIGURE 22.21 Last bottom pattern 6 degree axis, corrected to 2 degrees.

According to Phala (2009), 89% of school children (surveyed in 2002) experienced foot pathologies attributable to incorrectly shaped footwear, and two morphology studies in South Africa (Thompson and Zipfel 2005; Rajah 2006) found geometry differences in foot morphology in comparison to a standard inflare-shaped last.

Several studies reveal variation in foot morphology between populations (Hawes et al. 1994; Anil et al. 1997; Baba 1975; Benard and Stephens 1979; Thompson and Zipfel 2005). Pedal axial geometry studies have been conducted in Japan (Kouchi 1995, 1996) in which the majority of Japanese feet were found to be "outflared" with reference to the "conventional" shoe axis inflare of 6 degrees. In a study of feet in Hong Kong, Luximon (2001) found that the mean inflare angle for the sampled Chinese population was 3.2 degrees. Recent analysis of 3D foot images in South Africa has shown divergence of footwear axial design from natural foot morphology, specifically with regard to the anatomical longitudinal axis of the foot. The South African population mean inflare angle is 1.9 degrees (Thompson 2006).

To examine a 3D foot image for the longitudinal axis, a straight axis indicating the longitudinal axis of the foot should be inserted by extension of the heel bisector. Next, the tread axis should be inserted (axis along which the ball of the foot flexes; indicated by a line joining the center of the inner joint [first metatarsophalangeal joint] to the center of the outer joint [fifth metatarsophalangeal joint]). The tread axis line should be bisected and joined to the bisection of the heel, thereby forming the line representing the last axis (termed "swing" or "inflare" because it is placed inwardly toward the big toe). The angle between the two axes should be measured in degrees.

Footwear with 6 degrees inflare (this is best examined by turning the last or footwear over to analyze the axis on the last bottom or sole of the footwear) assumes that the arch dome will be positioned over the inner quarter of a shoe in the region of the medial longitudinal arch. This is only suitable for high arched feet or curved feet such as found in metatarsus adductus.

Footwear designed on a natural anatomical model should be based on a last axis that closely matches the foot axis, in order to promote natural foot function. This is necessary since, from the time the heel strikes the ground, the alignment of the heel seat and the rest of the foot bed acts to guide the foot in the direction of travel.

Research will need to establish how well a straight axis foot bed will guide juvenile adducted feet into more efficient and natural foot function by enabling better balance of muscle action.

An increasing number of footwear manufacturers have adopted the 2 degree inflare axial alignment model for comfort footwear design for adults. Podiatrists recommend 0 degrees of inflare for children's and adolescent's shoes.

A manual method of calculation of inflare angle (by inserting the axial lines described herein onto outlines of both the feet and insole or last bottom patterns) can be applied for assessment of any existing footwear last bottom pattern or insole pattern in combination with foot measurement, for prescription purposes.

22.8.5 Big Toe Alignment in Footwear Design

To preserve the natural function of the hallux or big toe, the last design as well as the design of the upper should honor the natural straight alignment of the big toe with the alignment of the first metatarsal bone. Placement of the upper across the forefoot must hold the foot across the joints and should not grip the foot any tighter than 5 mm less than the joint girth, so as not to impact on the blood or nerve supply. If the last shape is curved away from the big toe in the toe region, this will place torsion on the big toe joint. If sandal straps are placed ahead of the inner joint (first metatarsophalangeal joint), then adductory torsion of the big toe (toward the second toe) will occur. Over time, the adductory torsion will accelerate the formation of a bunion in a wearer whose genetic bone structure predisposes them to such deformity.

22.8.6 Proportional Fit and the Need for Ball Flexibility

According to Rossi and Tennant (1984), attention should be paid to the medial heel-to-ball measurement so that the correct proportional fit is achieved (Figure 22.22). Different heel-to-ball ratios in feet that are the same length can be a natural consequence of skeletal variation, but also of different arch heights in foot types such as pes planus (flat foot) and pes cavus (high arched foot). In pes planus, the arch is lower and therefore the heel-to-ball length is proportionately longer than the heel-to-ball length in a pes cavus foot (Figure 22.22).

As shown in Figure 22.22, a mismatch in proportional fit in a heeled shoe will give rise to muscle tension in the unsupported portion of the mid foot (B). Continuous, unrelieved muscle tension will cause muscles to spasm, resulting in pain (Guyton and Hall 1997). Population-specific arch curvature data from 3D anthropometric surveys are critical to ensure that last makers utilize the correct mean heel-to-ball ratio when preparing lasts for footwear manufacture.

In one study, analysis of 500 3D foot images showed that there was a 20 mm variance in heel-to-ball length, indicating the need for a zone of flexibility across the tread axis (as shown in Figure 22.22), so that the foot can flex at the ball joint irrespective of whether the flex axis is ahead of the last tread or behind it. The mean proportion of heel to ball to ball to toe was found to be 72:28 and not 66:33 (Thompson 2006).

22.8.7 Cost of Pain and Discomfort

Studies show that pain and discomfort factors can seriously affect concentration, thereby adversely affecting composure, interaction, and job performance (Katz 2002). Cost studies indicate that 76% of lost productive time is attributable to reduced performance while at work, not by work absence (Stewart et al. 2003). Chronic pain can give rise to depressed psychological states that, in turn, adversely impact mood and motivation (Gaskin et al. 1992; Mongini et al. 2004). Low grade,

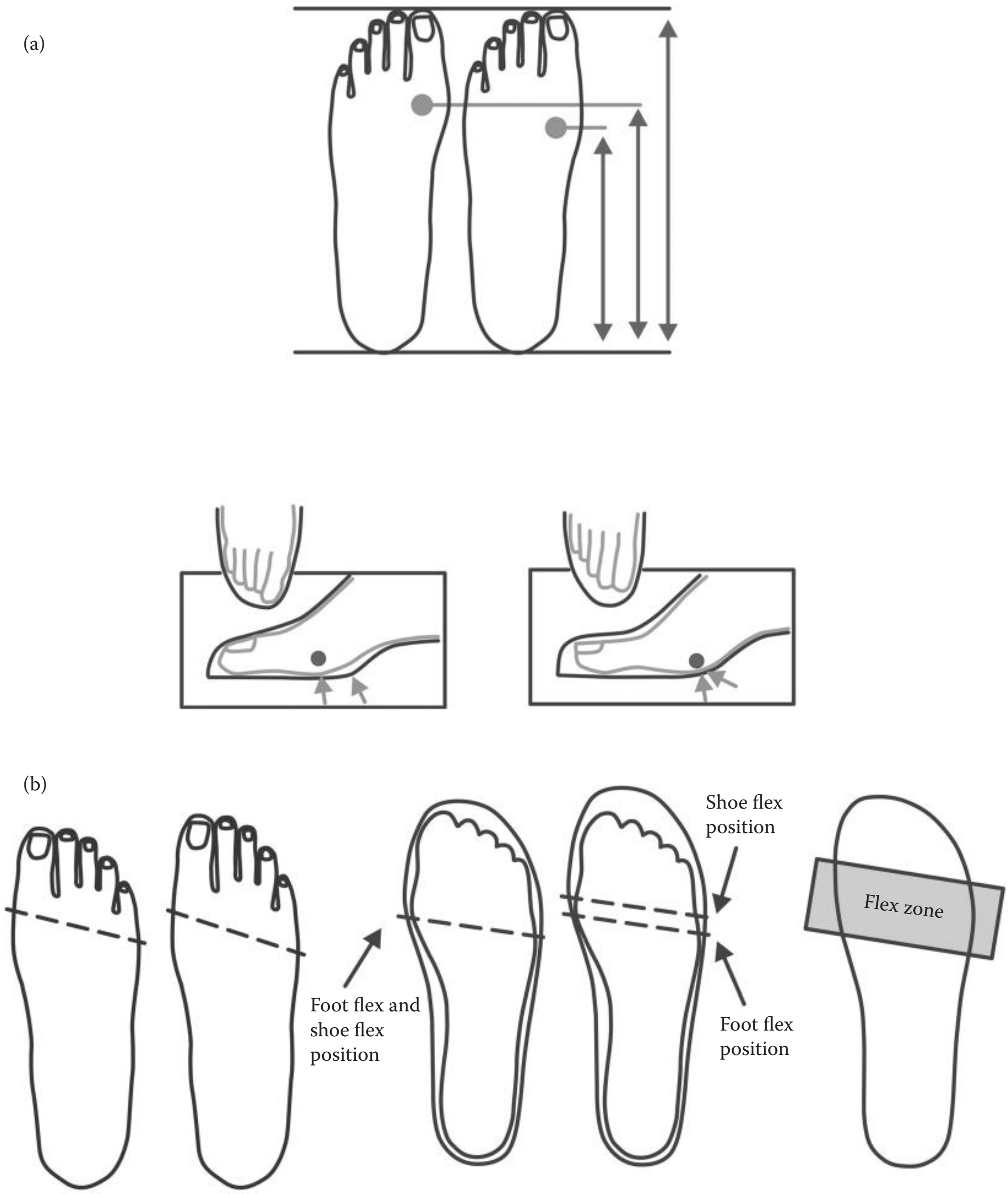


FIGURE 22.22 Proportional fit for heel-to-ball ratio and flexibility zone. (After Rossi, W.A. and Tennant, R., *Professional Shoe Fitting*, National Shoe Retailers Association, New York, 1984.)

constant foot pain can negatively influence mood and work performance. In terms of preventative care, the development of good footwear fit can positively impact on both psychological and physical factors affecting productivity and quality of life.

22.9 CONCLUSION

The advent of 3D computer scanning and CAD models has highlighted the importance of human factors in the design of footwear. In this chapter, aspects of morphology and function of the human foot are presented as factors that should be applied in the design of footwear that is intended to fit and function as closely as the foot itself. Lasts based on 3D measurement of representative populations allow natural foot function by respecting the morphology, anatomy, and function of specific foot populations. Axial alignment theory in last design is proposed as a necessary factor for improved footwear fit and function.

GLOSSARY

abduction: Motion away from the midline of the foot that occurs in the transverse plane around an axis that lies 90 degrees to the transverse plane and at the intersection of the coronal and sagittal planes.

adduction: Motion toward the midline of the foot that occurs in the transverse plane around an axis that lies 90 degrees to the transverse plane and at the intersection of the coronal and sagittal planes.

allowance: In adult shoes, the additional provision in size for foot stretch or expansion on weight bearing. Also the extra dimension allowed on the last for foot stretch or expansion on weight bearing. In fitting children's shoes, the extra length or width allowed for foot growth.

anthropometry: The branch of human science that deals with body measurements.

back part: Term generally used in South African industry for the back cone of a last.

ball: In the foot, the ball comprises the heads of the five metatarsal bones and the surrounding tissue. On the shoe, the ball is the corresponding area or section. Along with the heel, the ball represents one of the two primary weight bearing and tread sections of the foot and shoe.

ball girth: A measurement around the ball of the foot or last to determine shoe and last width and volume allowance inside the shoe. Also known as joint girth; a key measurement in last making.

CAD Abbreviation for computer-aided design.

CAM Abbreviation for computer-aided manufacture.

claw toes: Curvature of the toes in the coronal or frontal plane.

clip: The tightness of shoe fit on the last around the topline; to fit tightly or snugly on the last; the gripping action of a shoe on the foot by virtue of its shaping and dimensions.

cone: (1) The part of the last corresponding to the foot's instep; important in shaping the shoe for proper fit. (2) The upper and center portion of the last, divided into two sections, front and back cones. See also *front cone*.

coronal: The frontal plane of alignment of the body or parts thereof.

dorsiflexion: Motion toward the body that occurs in the sagittal plane around an axis that lies 90 degrees to the sagittal plane and at the intersection of the coronal and transverse planes.

elevation: An angle used, in conjunction with the azimuth angle, to define the position of an object in space relative to a specific observation point in 3D orientation.

eversion: Motion away from the midline of the body, occurring in the coronal plane around an axis that lies 90 degrees to the coronal plane and at the intersection of the transverse and sagittal planes.

extensor: Muscles located on the top surface of the foot that act to elevate the front of the foot in relation to the heel.

fashion allowance: In adult shoes, the allowance of one part of the last for a fashion detail, e.g., extra long toe box for elongated pointed toe escarpine styles.

feather edge: A very thin sole edge used mostly on women's fashion shoes. The term also applies to some shoe components such as counters.

flare: To curve or contour, as with an inflare or outflare last. Used either as a styling feature or for therapeutic shoe design for a foot correction.

flexion: The bend action of the foot across the ball, or of a shoe or outsole across the ball and vamp; the degree of the flex action is an indication of the functional normalcy of the foot or the walking ease of the shoe.

front cone: The portion of the last cone between the V-cut or thimble in the center and the vamp point on the top surface behind the toes. See also *cone.*

gait: Term used to describe the manner of human locomotion.

gait cycle: Sequence of movement phases that make up two sequential steps in human locomotion. The two main phases are "stance" (in which the foot is planted on the support surface and takes weight) and "swing" (in which the foot is non-weight bearing and is moving forward toward the next heel strike). The gait cycle begins when one foot contacts the ground and ends when that foot contacts the ground again. Thus, each cycle begins at initial contact with a stance phase and proceeds through a swing phase until the cycle ends with the limb's next initial contact. Stance phase accounts for approximately 60%, and swing phase for approximately 40%, of a single gait cycle.

Each gait cycle includes two periods when both feet are on the ground: The first period of double limb support begins at initial contact, and lasts for the first 10%–12% of the cycle. The second period of double limb support occurs in the final 10%–12% of stance phase. As the stance limb prepares to leave the ground, the opposite limb contacts the ground and accepts the body's weight. The two periods of double limb support account for 20%–24% of the gait cycle's total duration.

girth: Any of several circumference measurements taken on the last, such as around the ball, waist, and instep; or similar measurements on the foot. Girth allowance on the last differs depending on needs, e.g., closed tab boot has a wider girth allowance than an open tab boot.

GRF Abbreviation for ground reaction force; see *ground reaction force***.**

ground reaction force: A force equal in magnitude and opposite in direction to the force that the body exerts on the supporting surface through the foot.

hallux: Plural *halluces.* Anatomical name for the big toe.

heel: The raised component under the rear of the shoe, consisting of any of a wide variety of shapes, heights, styles, and materials. The raised heel has origins dating back at least 3000 years and was used in a utility manner to prevent the feet of horsemen from slipping out of the stirrup, and also to increase the wearer's stature and status. The modern high heel (two or more inches in height) dates back to the sixteenth century and has evolved into a primary fashion feature in a shoe for women.

heel curve: The back curve of a shoe from heel seat to the top rim to conform to the back curve of the foot. The curve shape varies in accord with heel height, style, or construction of the shoe or boot. The heel curve must be precise to avoid shoe slippage or biting at the heel. Also known as *back curve.*

heel pitch: The vertical slant or angle of the heel at the rear from heel seat to foot; not to be confused with the *heel angle.*

heel height: The height, floor to shank, measured at the heel breast. Heel height is measured in increments of one-eighth of an inch. Hence an 8/8 heel is one inch, a 20/8 is two and a half inches, and so on.

heel seat: The flat or slightly cupped section of the shoe on which the foot's heel rests; also the section of the shoe to which the heel is attached.

instep: The top inner portion of the foot at its crest, formed by the articulations of the bases of the first three metatarsal bones with the navicular bone and the first two cuneiform bones.

instep girth: The circumference around the foot at the instep, an important last measurement.

inversion: Motion toward the midline of the body, occurring in the coronal plane around an axis that lies 90 degrees to the coronal plane and at the intersection of the transverse and sagittal planes.

joint girth: See *ball girth.*

last: The plastic, metal, or wooden foot-shaped form over which the shoe is made to conform to the prescribed shape and size of the shoe. Also used as a verb to describe the process or action of shaping the shoe to the last.

lasting: The operations in the factory involved in forming all parts of the shoe to the last, including such special operations as toe lasting, side lasting, and heel seat lasting.

length: The length measurement of the foot from the back of the heel to the tip of the longest toe; also the length of the shoe from heel to toe tip but not including the shoe's sole.

length allowance: Additional length added to the last to allow for fashion or an extended toe recede slope; allowance of size for foot stretch or expansion on weight bearing.

osseous: Bone or of bone.

pes cavus: Medical umbrella term for a foot with a high arch or humped instep, irrespective of etiology.

pes planus: Medical umbrella term for a flat foot with a lowered and flattened medial longitudinal arch, irrespective of etiology.

pitch: Also known as last pitch or heel pitch.

plantar: Under surface; in scanning a weight-bearing foot, it is the surface in contact with the load-bearing surface, not visible while the foot is weight bearing.

plantarflexion: Motion away from the body that occurs in the sagittal plane around an axis that lies 90 degrees to the sagittal plane and at the intersection of the coronal and transverse planes.

pronation: A triplanar movement along the long axis of the foot consisting of eversion, abduction, and dorsiflexion.

recede: The part of the closed shoe toe shape that extends beyond the end of the toe of the foot, often slanted forward and downward or tapered.

seat: See *heel seat.*

size grading: The increments of size progression in shoe sizes or widths. In the metric system, the size progression is in centimeters. In the American sizing system, length is measured in one-sixth of an inch per half size and one-third of an inch per full size; or one-quarter inch for each width change.

stick length: Length derived from using a stick measure; the overall length of the last measured with a last size stick.

supination: A triplanar movement along the long axis of the foot consisting of inversion, adduction, and plantarflexion.

swing: The curvature of the outer rim of the outsole, or on a last.

3D Abbreviation for three dimension or three dimensional.

toe spring: The elevation of the under surface of the sole at the toe to give the sole a slight rocker effect for an easier step. The amount of toe spring (built into the last) depends on shoe style, sole thickness, and heel height.

topline: The top rim of the shoe's upper.

topline clip: The amount of tightness of shoe fit on the last around the topline; to fit tightly or snugly on the last.

tread: (1) The widest part across the ball of the foot on the last; (2) the area of the sole of the shoe that comes into contact with the ground for walking.

upper: All the parts or sections (vamp, quarters, linings, etc.) above the sole of the shoe that are stitched or otherwise joined together to become a unit, and then attached to the insole and outsole.

valgus: Valgus of the foot or part of the foot means a fixation of the part in a position it would assume if everted. It is a frontal plane fixation in which the plantar surface of the foot is directed away from the midline of the body.

REFERENCES

Adrian, K.C. 1991. *American Last Making.* St. Louis, MI: Brown Shoe Company.

Anderson, M., Blais, M., and Green, W.T. 1956. Growth of the normal foot during childhood and adolescence. *American Journal of Physical Anthropology* 14:287–308.

Anil, A., Peker, T., Turgut, H.B., and Ulukent, S.C. 1997. An examination of the relationship between foot length, foot breadth, ball girth, height and weight of Turkish university students aged between 17 and 25. *Anthropologischer Anzeiger* 55 (1): 79–87.

Arlen, D.I. 1984. Consumer survey on footwear: An examination of purchasing practices. *Journal of the American Podiatry Association* 74 (5): 247–53.

Baba, K. 1975. Foot measurement for shoe construction with reference to the relationship between foot length, foot breadth, and ball girth. *Journal of Human Ergology (Tokyo)* 3 (2): 149–56.

Backhouse, K.M., and Hutchings, R.T. 1989. *A Colour Atlas of Surface Anatomy*. London: Wolfe Medical Publications.

Beers, M.H., and Berkow, R. (eds.). 1999. *The Merck Manual of Diagnosis and Therapy*, 17th ed. Whitehouse Station, NJ: Merck Research Laboratories.

Bell, G.H., Davidson, J.N., and Scarborough, H. 1968. *Textbook of Physiology and Biochemistry*, 7th ed. Edinburgh: Churchill Livingstone.

Benard, M.A., and Stephens, D.G. 1979. A racial comparison of morphology in the lower extremity: A preliminary study. *Journal of the American Podiatry Association* 69 (5): 287–95.

Bleck, E.E. 1983. Metatarsus adductus: Classification and relationship to outcomes of treatment. *Journal of Paediatric Orthopaedics* 3 (1): 2–9.

Bojsen-Møller, F., and Lamoreux, L. 1979. Significance of free dorsiflexion of the toes in walking. *Acta Orthopaedica Scandinavica* 50:471–79.

Burkett, L.N., Kohrt, W.M., and Buchbinder, R. 1985. Effects of shoes and foot orthotics on VO_2 and selected frontal plane knee kinematics. *Medicine and Science in Sports and Exercise* 17 (1): 158–63.

Cavanagh, P.R. (ed.). 1980. *The Running Shoe Book*. Mountain View, CA: Anderson World.

Chantelau, E., and Gede, A. 2002. Foot dimensions of elderly people with and without diabetes mellitus – A data basis for shoe design. *Gerontology* 48 (6): 408.

Chantelau, E., and Haage, P. 1994. An audit of cushioned diabetic footwear: Relation to patient compliance. *Diabetic Medicine* 11 (1): 114–16.

Cheskin, M.P. 1987. *The Complete Handbook of Athletic Footwear*. New York: Fairchild Publications.

Dawber, R., Bristow, I., and Mooney, J. 1996. *The Foot: Problems in Podiatry and Dermatology*. London: Martin Dunitz.

De Berker, D., Bristow, I., Baran, R., and Dawber, R. 2002. *Nails Appearance and Therapy*. 2nd ed. London: Martin Dunitz.

Ergotech [Ergonomics Technologies]. (n.d.). Available from http://www.armscorbusiness.com/SubSites/ERGO/ERG02_01.asp (accessed 15 January 2006).

Ferrari, J., Hopkinson, D.A., and Linney, A.D. 2004. Size and shape differences between male and female foot bones. *Journal of the American Podiatric Medical Association* 94 (5): 434–52.

Frey, C., Thompson, F., Smith, J., Sanders, M., and Horstman, H. 1993. American Orthopaedic Foot and Ankle Society women's shoe survey. *Foot & Ankle* 14 (2): 78–81.

Frost, H.M. 1992. The role of changes in mechanical usage set points in the pathogenesis of osteoporosis. *Journal of Bone and Mineral Research* 7:253–61.

Fuller, E.A. 1994. A review of the biomechanics of shoes. *Clinics in Podiatric Medicine and Surgery* 11 (2): 241–58.

Gaskin, M.E., Greene, A.F., Robinson, M.E., and Geisser, M.E. 1992. Negative affect and the experience of chronic pain. *Journal of Psychosomatic Research* 36 (8): 707–13.

Guyton, A.C., and Hall, J.E. 1997. *Human Physiology and Mechanisms of Disease*. Philadelphia: W.B. Saunders.

Hardin, E.C., Van den Bogert, A.J., and Hamill, J. 2004. Kinematic adaptations during running: Effects of footwear, surface, and duration. *Medicine & Science in Sports & Exercise* 36 (5): 838–44.

Hargens, A.R. 1981. Introduction and historical perspectives. In *Tissue Fluid Pressure and Composition*, ed. A.R. Hargens, 1–8. Baltimore: Williams and Wilkins.

Hawes, M.R., and Sovak, D. 1994. Quantitative morphology of the human foot in a North American population. *Ergonomics* 37 (7): 1213–26.

Hawes, M.R., Sovak, D., Miyashita, M., Kang, S., Yoshihuku, Y., and Tanaka, S. 1994. Ethnic differences in forefoot shape and the determination of shoe comfort. *Ergonomics* 37 (1): 187–96.

Hill, L.M. 1958. Changes in the proportion of the female foot during growth. *American Journal of Physical Anthropology* 16:349.

Hitzeroth, H.W. 1986. On the genetic interrelationships of South African Negroes. *American Journal of Physical Anthropology* 69 (3): 389–401.

Houston, V.L. 2002. *Biomechanical Studies and Optical Digitizer Development for Enhanced Orthopedic Footwear.* Annual Report/DAMD17-00-1-0577. Fort Detrick, MD: U.S. Army Medical Research and Material Command.

Hughes, J., Clark, P., and Klenerman, L. 1990. The importance of the toes in walking. *The Journal of Bone and Joint Surgery (British)* 72-B (2): 245–51.

Hughes, J.R. 1995. Footwear assessment. In *Assessment of the Lower Limb*, eds. L.M. Merriman and D.R. Tollafield, 227–46. Edinburgh: Churchill Livingstone.

Igbigbi, P.S., and Mutesasira, A.N. 2003. Calcaneal angle in Ugandans. *Clinics in Anatomy* 16 (4): 328–30.

Jackson, P. 1996. Footloose in archaeology. *Journal of British Podiatric Medicine* 51 (5): 67–70.

Jackson, R. 1990. The Chinese foot-binding syndrome: Observations on the history and sequelae of wearing ill-fitting shoes. *International Journal of Dermatology* 29 (5): 322–28.

Jarrett, B.A., Manzi, J.A., and Green, D.R. 1980. Interossei and lumbricales muscles of the foot: An anatomical and functional study. *Journal of the American Podiatry Association* 70 (1): 1–13.

Johnson, J. 1994. Footwear alleviates aches, fatigue through better fit, shock absorption. *Occupational Health & Safety* 63 (3): 68–69.

Kadambande, S., Khurana, A., Debnath, U., Bansal, M., and Hariharan, K. 2006. Comparative anthropometric analysis of shod and unshod feet. *The Foot* 16:188–91.

Katz, W.A. 2002. Musculoskeletal pain and its socioeconomic implications. *Clinics in Rheumatology* 21, Supplement 1: S2–4.

Kerrigan, D.C., Thirunarayan, M.A., Sheffler, L.R., Ribaudo, T.A., and Corcoran, P.J. 1996. A tool to assess biomechanical gait efficiency; a preliminary clinical study. *American Journal of Physical Medicine & Rehabilitation* 75 (1): 3–8.

Kidd, R. 1995. An investigation into the patterns of morphological variation in the proximal tarsus of selected human groups, apes and fossils: A morphometric analysis. Doctoral thesis, University of Western Australia.

Kidd, R.S., and Oxnard, C.E. 1997. Patterns of morphological discrimination in the human talus: A consideration of the case of negative function. In *Perspectives in Human Biology*, eds. M. Henneberg and L. Freedman, 57–69. Perth: Centre for Human Biology; Singapore: World Scientific Publishing.

Klenerman, L., Nissen, K.I., and Baker, H. 1976. Common causes of pain in the region of the foot. In *The Foot and its Disorders*, ed. L. Klenerman, 135–37. Oxford: Blackwell Scientific.

Konz, S., and Subramanian, V. 1989. Footprints. In *Advances in Industrial Ergonomics and Safety I*, ed. A. Mital, 686–87. London: Taylor & Francis.

Kouchi, M. 1989. The sexual difference in foot shape. *Journal of the Society of Biomechanisms* 13:142–47.

———. 1995. Analysis of foot shape variation based on the medial axis of foot outline. *Ergonomics* 38 (9): 1911–20.

———. 1996. Relation between the medial axis of the foot outline and 3D foot shape. *Ergonomics* 39 (6): 853–61.

Kouchi, M., and Mochimaru, M. 2008. Shoe size system in Japan. Digital Human Research Center. Available from http://www.dh.aist.go.jp/research/centered/foot/shoes.php.en (accessed January 20, 2010).

Krauss, I., Grau, S., Janssen, P., Maiwald, C., Mauch, M., and Horstmann, T. 2005. Gender Differences in Foot Shape. In *Proceedings of the 7th Symposium on Footwear Biomechanics*, eds. J. Hamill, E. Hardin, and K. Williams. Cleveland, OH: Footwear Biomechanics Group.

Kurz, M.J., and Stergiou, N. 2004. Does footwear affect ankle coordination strategies? *Journal of the American Podiatry Medical Association* 94:53–58.

Kusumoto, A., Suzuki, T., Kumakura, C., and Ashizawa, K. 1996. A comparative study of foot morphology between Filipino and Japanese women, with reference to the significance of a deformity like hallux valgus as a normal variation. *Annals of Human Biology* 23 (5): 373–85.

Lewis, C.P., Lavy, C.B., and Harrison, W.J. 2002. Delay in skeletal maturity in Malawian children. *British Journal of Bone and Joint Surgery* 84 (5): 732–34.

Liu, W., Miller, J., Stefanyshyn, D., and Nigg, B.M. 1999. Accuracy and reliability of a technique for quantifying foot shape, dimensions and structural characteristics. *Ergonomics* 42 (2): 346–58.

Lord, M., and Pratt, D.J. 1997. Footwear therapy. In *Clinical Skills in Treating the Foot*, ed. D.R. Tollafield and L.M. Merriman, 249–65. New York: Churchill Livingstone.

Lucock, L.J. 1972. Last Design and Foot Health. Lecture C10, SATRA Conference Proceedings. 'Foot Comfort and Health' Conference, Corby, UK.

Lumley, J.S.P. 1990. *Surface Anatomy: The Anatomical Basis of Clinical Examination*. Edinburgh: Churchill Livingstone.

Luximon, A. 2001. *Foot Shape Evaluation for Footwear Fitting*. Doctoral thesis published in Hong Kong University Library Institutional Repository, Item 1783.1/1557.

Luximon, A., Goonetilleke, R.S., and Tsui, K.L. 2003. Foot landmarking for footwear customization. *Ergonomics* 46 (4): 364–83.

Macfarlane, R.M., and Jeffcoate, W.J. 1997. Factors contributing to the presentation of diabetic foot ulcers. *Diabetic Medicine* 14 (10): 867–70.

Mann, R.A., and Hagy, J.L. 1979. The function of the toes in walking, jogging and running. *Clinics in Orthopaedics* 142:24–29.
Mantaura, A., and Bryant, H. 1989. Nail disorders due to trauma and other acquired conditions of the nail. *Clinics in Podiatric Medicine and Surgery* 6 (2): 347–54.
McGlamry, E.D. 1978. Shoes can be therapeutic. *Journal of the American Podiatry Association* 68 (4): 232–34.
McKears, D.W., and Owen, R.H. 1979. *Surface Anatomy for Radiographers*. Bristol: John Wright & Sons.
Menz, H.B., and Sherrrington, C. 2000. The footwear assessment form: A reliable clinical tool to assess footwear characteristics of relevance to postural stability in older adults. *Clinics in Rehabilitation* 14:657–64.
Miller, R.G., and Redwood, S.R. (eds.). 1989. *Manual of Shoemaking,* 2nd ed. 6th Impression. Bristol: C.&J. Clark Ltd.
Mongini, F., Ciccone, G., Deregibus, A., Ferrero, L., and Mongini, T. 2004. Muscle tenderness in different headache types and its relation to anxiety and depression. *Pain* 112 (1–2): 59–64.
Morio, C., Lake, M.J., Gueguen, N., Rao, G., and Baly, L. 2009. The influence of footwear on foot motion during walking and running. *Journal of Biomechanics* 42:2081–88.
Nancarrow, S.A. 1999. Footwear suitability scale: A measure of shoe fit for people with diabetes. *Australian Journal of Podiatric Medicine* 33 (2): 57–62.
Ness, M.E., Long, J., Marks, R., and Harris, G. 2008. Foot and ankle kinematics in patients with posterior tibial tendon dysfunction. *Gait Posture* 27 (2): 331–39.
Özdemir, H., Söyüncü, Y., Özgörgen, M., and Dabak, K. 2004. Effects of changes in heel fat pad thickness and elasticity on heel pain. *Journal of the American Podiatry Medical Association* 94:47–52.
Parham, K.R., Gordon, C.C., and Bensel, C.K. 1992. *Anthropometry of the Foot and Lower Leg of U.S. Army Soldiers: Fort Jackson, SC – 1985*. Technical Report Natick/TR-92/028. Natick, MA: U.S. Army Natick Research, Development and Engineering Center.
Patriquin, M.L., Loth, S.R., and Steyn, M. 2003. Sexually dimorphic pelvic morphology in South African whites and blacks. *Homo* 53 (3): 255–62.
Phala, G. 2009. Podiatry Positional Document: State Health. June 30, 2009. South African Podiatry Association.
Phillips, R.D. 2000. The normal foot. *Journal of the American Podiatric Medical Association* 90 (7): 342–45.
Rai, J., Bansal, V.P., and Prakash, S. 1978. Dimensional study of arch height and girths of foot in Panjabi children. *Indian Journal of Medical Research* 68:121–29.
Rajah, F. 2006. The average heel to ball index. Unpublished Bachelors thesis, University of Johannesburg. Johannesburg, South Africa.
Rendall, G.C., Thomson, C.E., and Boyd, P.M. 1997. Disorders of the adult foot. In *Neale's Common Foot Disorders*, 5th ed. eds. D. Lorimer, G. French and S. West, 75–82. New York: Churchill Livingstone.
Riches, K. 1980a. Lecture 1: Shoe styles and terminology. In *Footwear Product Knowledge*, ed. K. Riches, 1–44. Port Elizabeth: Ken Riches Footwear Consultants.
———. 1980b. Lecture 3: The human foot, the last on which the shoe is made; and foot and shoe sizing. In *Footwear Product Knowledge*, ed. K. Riches, 1–46. Port Elizabeth: Ken Riches Footwear Consultants.
Robinette, K.M., Daanen, H., and Paquet, E. 1999. The Caesar Project: A 3D surface anthropometry survey. In *Proceedings of Second International Conference on 3D Imaging and Modeling* (3DIM'99), 380–86. Ottawa: National Research Council. ISBN 0-7695-0062-5.
Root, M.L., Orien, W.P., and Weed, J.H. 1977. *Normal and Abnormal Function of the Foot*, 1st ed. Los Angeles: Clinical Biomechanics Corporation.
Rossi, W.A. 1980. The last: Heart of the shoe. *Journal of the American Podiatry Association* 70 (10): 533–34.
———. 1983. The enigma of shoe sizes. *Journal of the American Podiatry Association* 73 (5): 273–74.
———. 1985. The seven basic shoe styles. *Journal of the American Podiatric Medical Association* 75 (3): 169–71.
———. 1988. The futile search for the perfect shoe fit. *Journal of Testing and Evaluation* 16 (4): 393–403.
———. 2000. *The Complete Footwear Dictionary*, 2nd ed. Florida: Krieger.
———. 2003. The foot: Mother of humanity. *Podiatry Management* 22 (4): 189–214.
Rossi, W.A., and Tennant, R. 1984. *Professional Shoe Fitting*. New York: National Shoe Retailers Association.
Rys, M., and Konz, S. 1994. Standing. *Ergonomics* 37 (4): 677–87.
Schuster, R.O. 1978. The effects of modern footgear. *Journal of the American Podiatry Association* 68 (4): 235–41.
Seale, K.S. 1995. Women and their shoes: Unrealistic expectations? *Instructional Course Lectures* 44:379–84.
Seibel, M.O. 1988. *Foot Function: A Programmed Text.* Baltimore: Williams & Wilkins.
Smith, S.A., and Norris, B.J. 2004. Changes in the body size of UK and US children over the past three decades. *Ergonomics* 47 (11): 1195–1207.
Stamm, T.T. 1964. *A Guide to Orthopaedics*, 62–63, 2nd ed. Oxford: Blackwell Scientific.

Steinberg, A.G., Jenkins, T., Nurse, G.T., and Harpending, H.C. 1975. Gammaglobulin groups of the Khoisan peoples of Southern Africa: Evidence for polymorphism for a GM1,5,13,14,21 haplotype among the San. *American Journal of Human Genetics* 27 (4): 528–42.

Stewart, S.F. 1972. Footgear – its history, uses and abuses. *Clinical Orthopaedics and Related Research* 88:119–30.

Stewart, W.F., Ricci, J.A., Chee, E., Morganstein, D., and Lipton, R. 2003. Lost productive time and cost due to common pain conditions in the US workforce. *Journal of the American Medical Association* 290 (18): 2443–54.

Sullivan, L.H. 1947. The tall office building artistically considered. In *The Documents of Modern Art, Volume 4* [*Kindergarten Chats (revised 1918) and Other Writings*], ed. I. Athey, 202–13. New York: George Wittenborn Incorporated.

Tachdjian, M.O. 1990. *Pediatric Orthopaedics.* Volume I, 2nd ed. Philadelphia: W.B. Saunders.

Thompson, A.L.T. 2006. A South African podometric study: Does the shoe fit the foot? Unpublished Masters thesis, University of Johannesburg.

Thompson, A.L.T., and Zipfel, B. 2005. The unshod child into womanhood – forefoot morphology in two populations. *The Foot* 15 (1): 22–28.

Tobias, P.V. 2005. *Into the Past: A Memoir*. Johannesburg: Picador Africa.

Trinkaus, E. 2005. Anatomical evidence for the antiquity of human footwear use. *Journal of Archaeological Science* 32:1515–26.

Turner, J. 2006. *Sizing System, Designations and Marking for Boots and Shoes.* Technical Report ISO/TC 137:N101. Geneva: International Standards Organization.

Viladot, A. 1973. Metatarsalgia due to biomechanical alteration of the forefoot. *Orthopaedic Clinics of North America* 4 (1): 165–78.

Wunderlich, R.E., and Cavanagh, P.R. 2001. Gender differences in adult foot shape: Implications for shoe design. *Journal of Medicine & Science in Sports & Exercise* 33 (4): 605–11.

Zipfel, B. 2004. Morphological variation in the metatarsal bones of selected recent and pre-pastoral humans from South Africa. Doctoral thesis, University of the Witwatersrand.

Zipfel, B., and Berger, L.R. 2007. Shod versus unshod: The emergence of forefoot pathology in modern humans? *The Foot* 17:205–13.

Zipfel, B., and Kidd, R.S. 2008. Size and shape in a human foot bone from Klasies River main site, South Africa. *Palaeontologica Africana* 43:51–56.

Zipfel, B., Kidd, R., and Berger, L. 2003. Morphological variation in the metatarsus of selected modern and ancient Holocene people from South Africa [abstract]. *American Journal of Physical Anthropology* Supplement 36:231.

23 Science of Footwear Design

Ravindra S. Goonetilleke, Channa P. Witana, and Shuping Xiong

CONTENTS

23.1 INTRODUCTION

The right fit and point-of-sale comfort are primary factors when purchasing footwear (Cheskin 1987; Chong and Chan 1992; McEvoy 1996; Au and Goonetilleke 2005). Among 420 European consumers, it has been reported that 51.5% of males and 58.8% of females had fit-related issues with footwear (Piller 2002). Ill-fitting footwear contribute toward discomfort, foot deformities, and even injuries (Cavanagh 1980; Cheskin 1987; Clarks 1989) and researchers have been exploring ways to improve the foot–shoe compatibility, and thereby comfort, by investigating foot anthropometrics, biomechanics, and perceptual aspects. Recent developments in three-dimensional (3D) digitalization technologies (Treleaven 2004) and the development of footwear-specific CAD/CAM systems (Chen 1988; Bao, Soundar, and Yang 1994) are helping the drive toward improving compatibility through the use of mass customization methodologies (Viavor 2007). This chapter is aimed at providing an understanding of foot anthropometry and foot shape, so that they can be built into shoes that are comfortable to wear. A case study of how to design boots is also presented.

23.2 FOOT ANTHROPOMETRY

The shoe last is a mould that gives the shoe its shape and style. It should be designed giving due consideration to foot anthropometry (Baba 1975; Rossi 1983; Clarks 1989; Venkatappaiah 1997; Luximon 2001; Feng 2002) and foot biomechanics.

Foot dimensions, such as lengths, widths, heights, and girths, measured using simple devices like rulers, calipers, and tapes, and other special devices like the Brannock device or the Ritz Stick are frequently reported in many publications (Freedman et al. 1946; Rossi 1983; Bunch 1988; Hawes and Sovak 1994; Goonetilleke, Ho, and So 1997). In more recent years, laser scanners and other digitizing technologies have been used for the automatic measurement of feet (Liu et al. 1999; Kouchi 2003; Witana et al. 2006). However, the questions with regard to foot anthropometry are what to measure, where to measure, and how to measure. Unfortunately, foot dimensions have been researcher and/or organization specific. In other words, who measures the foot dictates what is measured. Foot length is a good case in point. Freedman et al. (1946) defined it to be the length from the heel to the longest toe tip along rectilinear ordinates; Pheasant (1988) defined it as the length parallel to the long axis of the foot, from the back of the heel to the tip of the longest toe; while Witana et al. (2006) defined foot length as the distance along the Brannock axis from pternion to the tip of the longest toe. Since a dimension depends on its measurement axis, it is necessary to develop a set of universal definitions for measuring the foot so that footwear designers and manufacturers have a unique standard.

A good discussion in relation to the reproducibility and repeatability of anthropometric measurements is provided by Roebuck (1995). Repeatability refers to the variability present in a measurement when one dimension is measured repeatedly by one person. Reproducibility, on the other hand, is the variability of the mean values of a dimension measured by several operators. Liu et al. (1999) proposed a technique to calculate 23 foot dimensions (8 lengths, 8 widths, and 7 heights) from the coordinates of 26 digitized points on the foot and the leg. All of their dimensions were based on an anatomically defined reference frame. Their results showed that the intra- and inter-rater reliabilities were high. Based on an extensive search of available definitions, Witana et al. (2006) have proposed a set of 18 foot dimensions (Figure 23.1). The 18 dimensions include 5 lengths (foot length, arch length, heel to medial malleolus, heel to lateral malleolus, heel to fifth toe), 4 widths (foot width, heel width, bimalleolar width, mid-foot width), 3 heights (medial malleolus height, lateral malleolus height, mid-foot height), and 6 girths (ball girth, instep girth, long heel girth, short heel girth, ankle girth, waist girth). Both intra- and inter-rater reliabilities had intraclass correlation coefficients (Shrout and Fleiss 1979), ICC (2, 1) > 0.84 for all 18 foot dimensions with the values being higher than those reported by Liu et al. (1999).

Many factors contribute toward the variations in each foot dimension, including within-subject factors, such as the side of foot and load on the foot, and between-subject factors, such as gender, age, and race. Luximon (2001) provides information on some aspects related to age and race. The three factors of side of foot, loading on foot, and gender will be presented here.

Even though the left and right feet are different in terms of foot length, width, and girth (Rys and Konz 1989), there are no significant ($p > 0.05$) differences between them for either males or females (Rys and Konz 1989; Cheng et al. 1997). The female mean foot length is approximately 91% that of males, while the foot volume of females is around 81% that of males. In other words, it is no surprise that the average female foot is shorter and slender compared to the male foot (Rys and Konz 1989; Wunderlich and Cavanagh 2001). However, the female foot is not just a scaled-down version of the male foot. Wunderlich and Cavanagh (2001) reported that after normalizing the female foot with respect to foot length, the calf height, plantar arch height, ankle circumference, and calf circumference are greater than the male foot. The load acting on the foot alters its shape. When half the body weight acts on each foot, the foot expands by around 3 mm relative to its "unloaded" condition (i.e., a person sitting with little or no load acting on the floor) in Chinese adults (Cheng et al. 1997; Xing et al. 2000).

23.3 SHOE FIT

A good fit is the result of having the right pressure between foot and shoe in different regions. In the USA, a customer's feet are measured using the Brannock (www.brannock.com) device to determine the foot length, arch length, and foot width so that the sales person can quickly find the shoe size that may fit the customer (Rossi and Tennant 2000). The instructions when using the Brannock device state that the correct shoe size has to be found by comparing the shoe size corresponding to the measured arch length and the shoe size corresponding to the heel-to-toe length. If the size that corresponds to the arch length and heel-to-toe length are the same, then the fitted size is unique. If the size corresponding to the arch length is larger than that corresponding to the heel-to-toe, then the shoe size to be chosen is the one corresponding to that of the arch length (www.brannock.com) as it is important that the metatarsophalangeal joint (MPJ) matches with the flex line of the shoe so that foot functioning is not impaired (Rossi and Tennant 2000). This process inevitably results

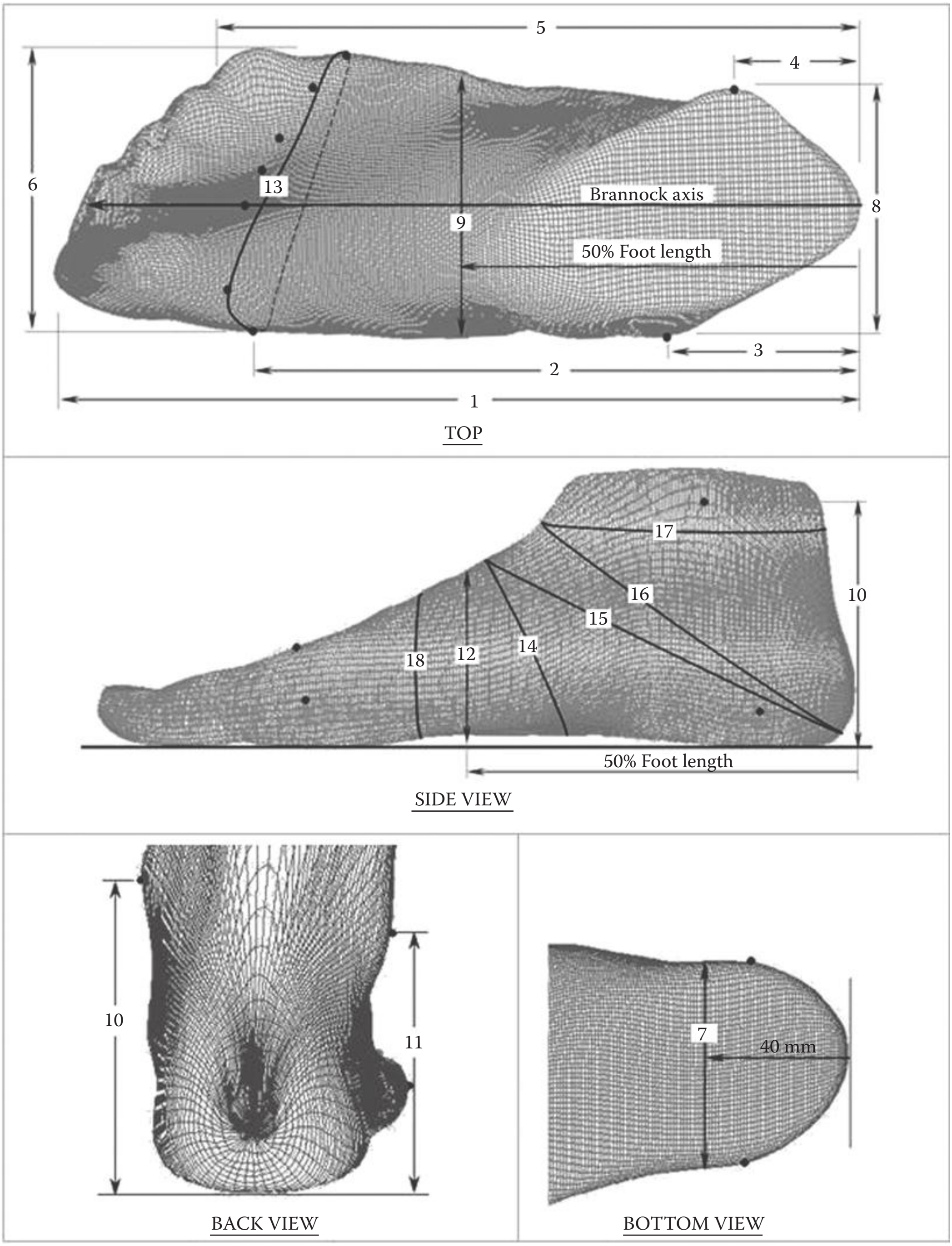


FIGURE 23.1 Eighteen foot dimensions measured in the study of Witana et al. (2006). 1–5: foot length, arch length, heel to medial malleolus, heel to lateral malleolus, heel to fifth toe; 6–9: foot width, heel width, bimalleolar width, mid-foot width; 10–12: medial malleolus height, lateral malleolus height, mid-foot height; 13–18: ball girth, instep girth, long heel girth, short heel girth, ankle and waist girth. (Adapted from Witana, C.P., et al., *International Journal of Industrial Ergonomics*, 36, 789, 2006.)

in a shoe that is longer than required, but allows proper flexing at the MPJ. Similarly, if the shoe size corresponding to the heel-to-toe length is larger than that of the shoe corresponding to the arch length, then the Brannock manufacturer recommends that the shoe size to be chosen is that corresponding to the heel-to-toe size, otherwise the shoe will be too short. However, in this scenario, the MPJ may not be aligned with the flex-groove of the shoe and hence foot functioning may be impaired. The Brannock device is just one way to select a "matching" size of shoe.

Jannise (1992) recommends evaluating the differences between the shoe and foot outlines to determine the degree of footwear fit rather than using measurements on the foot. However, the differences in the outlines have to be related to a person's subjective feel of tightness or looseness in order to know whether the fit is acceptable. Even though the allowable foot-shoe differences for some dimensions such as foot width and overall foot length are known (Jannise 1992; Frey et al. 1993), those allowances may not be applicable for all widthwise and lengthwise dimensions. The musculoskeletal structure in different regions of the foot (i.e., rearfoot, midfoot, and toes, as shown in Figure 23.2) is different and hence the resulting deformations in each region can be quite different (Rossi and Tennant 2000). Thus, it may be that the allowable foot-shoe differences at different locations on the foot may be quite different for a person to feel comfortable when wearing a shoe.

With the rapid advances in scanning technology, foot-shoe differences can be determined using 3D scans of the foot and the shoe-last shapes (Luximon, Goonetilleke, and Tsui 2003a) with a high accuracy and reliability with available scanning technologies (Gärtner et al. 1999; Blais et al. 2000) and with the use of efficient algorithms for matching 3D objects (Novotni and Klein 2001; Osada et al. 2001; Kos and Duhovnik 2002). However, the shape or dimensional differences (DD) alone may not be meaningful without a good understanding of a person's subjective feel of fit. Thus, there is no doubt that a good understanding of the foot-shoe DD and their effects on a person's perceived feel (i.e., level of tightness and looseness) in different regions of the foot, is rather important to improve the fit of footwear.

Generally, the predominant areas of misfit are on the two sides of the foot, the dorsal surface of the foot and the footbed. Hence, the fit on the medio-lateral sides will be considered from a perceptual standpoint, while the dorsal and footbed fits will be evaluated from a biomechanical and anthropometric viewpoint.

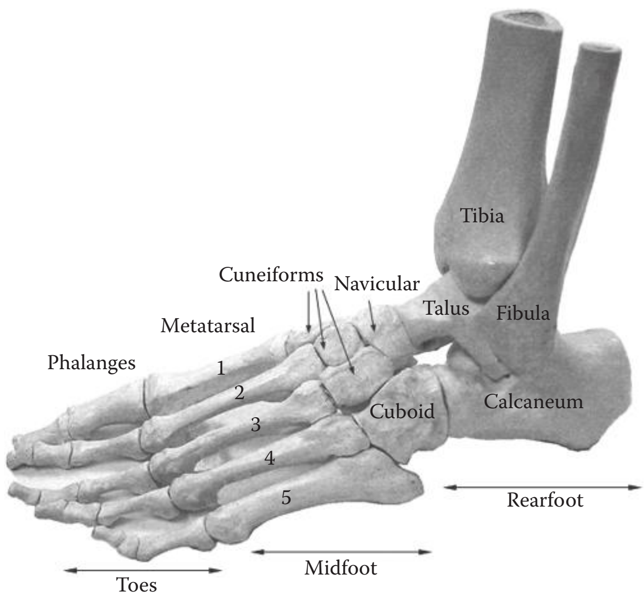


FIGURE 23.2 Bones on foot.

23.3.1 Medio-Lateral Fit

Witana, Goonetilleke, and Feng (2004) investigated the effects of foot-shoe differences on a person's perceived feel by comparing the two-dimensional (2D) outlines of feet and shoe lasts. The 2D outlines of the foot and the last were obtained from 3D laser scans. Figure 23.3 shows an outline of a left foot aligned with a size 8 dress shoe-last outline. In that study, the foot-shoe differences were quantified using the DD from each point on the foot to the last outline. The DD was computed as the shortest Euclidean distance, a special case of the Minkowski distance metric (Osada et al. 2001). Luximon, Goonetilleke, and Tsui (2003a) introduced the concept of negative and positive differences to distinguish whether the shoe was loose or tight. As the foot length and foot width of each person is different, the perimeter of the foot is normalized to be 100 and then the DD can be plotted as shown in Figure 23.4.

The prominent characteristics of the DD plot (Figure 23.4) are four local minimum points and one local maximum. Each of these five features (four minimums and one maximum) can be hypothesized to contribute toward the perceived fit. Given the similarity of the DD plots along the perimeter of each participant's foot, it is clear that the minimum points and the maximum point designate the critical regions of fit. The shape of the DD curve could be different with different designs or models of shoe. This is possibly one reason why some consumers prefer one style or one brand of shoe. The critical fit would be similar with the same brand and similar model of shoe. The DD on the medial and lateral sides of the forefoot are e_2 and e_3, respectively, while the differences on the medial and lateral sides of the midfoot are e_1 and e_4, respectively (Figure 23.4). The wearer's perceived feelings in different regions of the shoe (overall, forefoot, midfoot, and rearfoot) were recorded using a 7-point rating scale when wearing the dress shoes. The subjective rating for forefoot fit showed a high correlation with e_2 and $(e_2 + e_3)$. The linear regression of perceived forefoot fit with the DD (Figure 23.5) was as follows:

$$\text{Forefoot fit rating } (q4) = 0.434(e_2 + e_3) + 3.7 \quad R^2 = 0.8247, \tag{23.1}$$

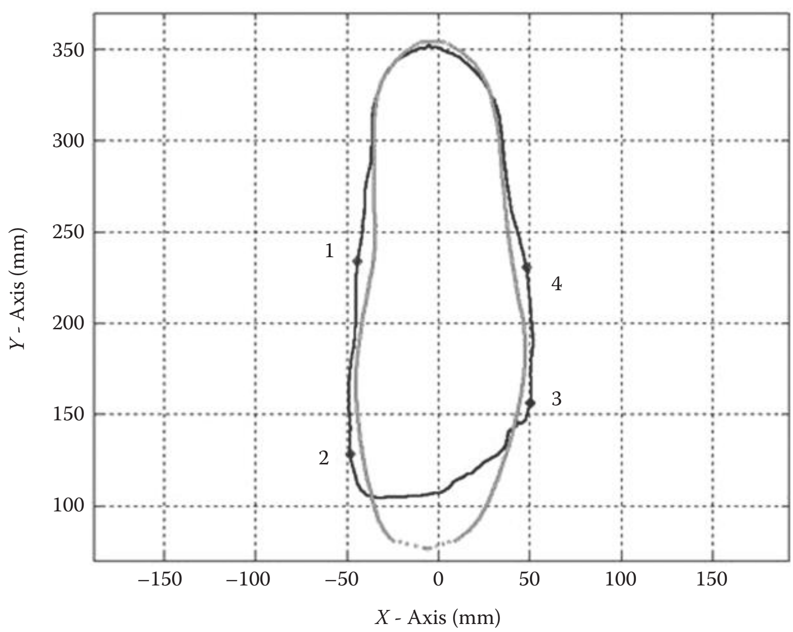


FIGURE 23.3 A left foot outline overlapped (positioned and aligned) with size 8 dress shoe-last outline.

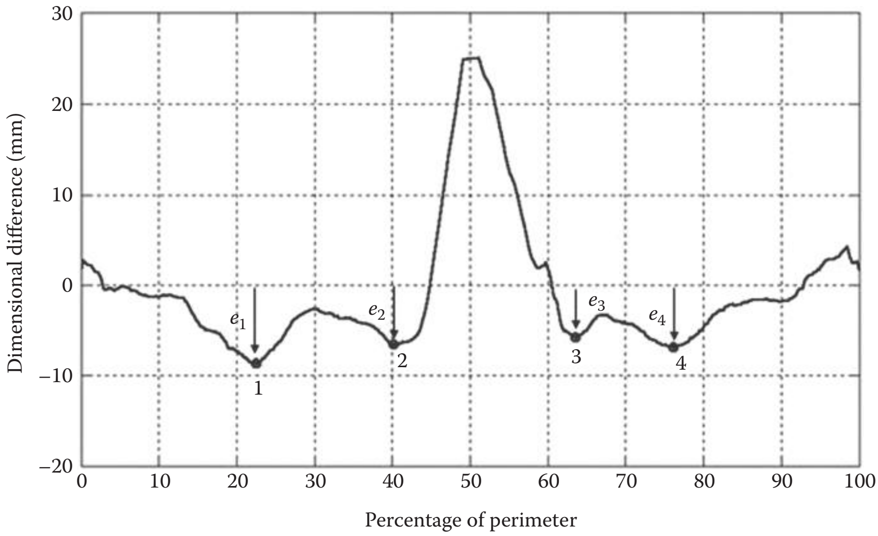


FIGURE 23.4 Dimensional difference between a participant foot and the size 8 dress shoe last along the normalized perimeter of the foot. Points 1, 2, 3, and 4 correspond to the local minimums. (Refer to Figure 23.3 for the locations of points 1, 2, 3, and 4 with respect to the foot.)

$$\text{Forefoot fit rating } (q4) = 0.758e_2 + 3.9 \quad R^2 = 0.9145. \tag{23.2}$$

Similarly, the subjective rating of midfoot fit showed a high correlation with e_4 and $(e_1 + e_4)$. The midfoot relationship with the corresponding differences (Figure 23.6) was as follows:

$$\text{Midfoot fit rating } (q5) = 0.63e_4 + 3.86 \quad R^2 = 0.9082, \tag{23.3}$$

$$\text{Midfoot fit rating } (q5) = 0.495(e_1 + e_4) + 7.2 \quad R^2 = 0.9907. \tag{23.4}$$

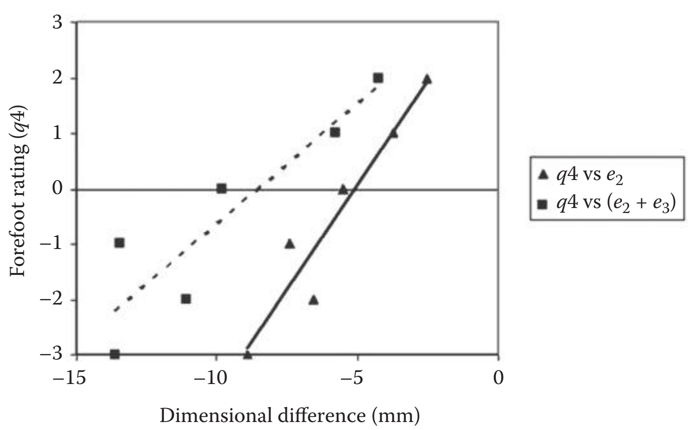


FIGURE 23.5 Relationship of forefoot fit rating with dimensional difference between foot outline and last outline.

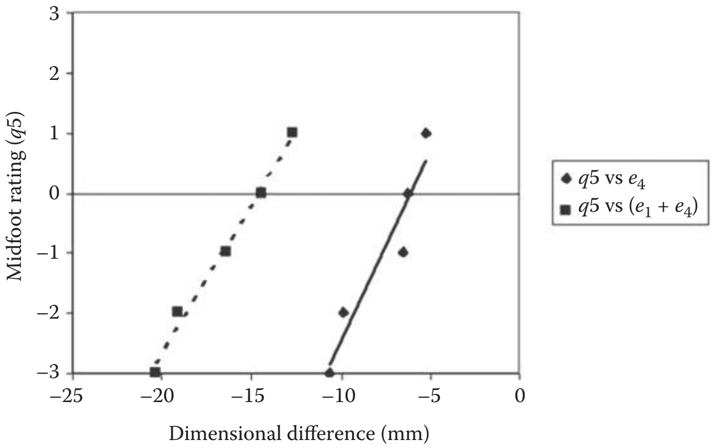


FIGURE 23.6 Relationship of midfoot fit rating with dimensional difference between foot outline and last outline for all shoes.

Witana, Goonetilleke, and Feng (2004) reported that a perfect fit (one that is neither tight nor loose) in the forefoot region can be achieved when the DD is around 5 mm on the medial side or around 8 mm on the width dimension. Similarly, the allowance for a neutral fit in the midfoot region requires a 7 mm DD on the lateral side or a 15 mm DD in the total width in the midfoot region (Figure 23.6).

Luximon, Goonetilleke, and Tsui (2003b) stressed the importance of supporting the foot at the right places, considering its structure. They proposed the use of eight landmarks to generate the foot outline with a known accuracy. Two of those landmarks seem to correspond well with two of the local minimum points, 1 and 4 (Figure 23.4). Knowing the importance of the four characteristic points, it is somewhat clear as to why the width dimension of a foot sometimes helps in footwear sizing. The distance between points 2 and 3 (d_{23}) on the foot and the distance between points 1 and 4 (d_{14}) on the foot (Figure 23.3) may be correlated with the foot width that is usually measured around the MPJ region. Thus, if the manufacturer does account for this correlation in the design of the shoe, the shoe can be "designed" to fit well on a person's foot. For feet that do not show such a strong correlation or for shoes that have not been designed with such a relation, the shoe-foot fit may not be perceived well. Thus, an improved fit may be obtained by considering d_{23} and d_{14} when designing footwear. Alternatively, the use of flexible materials in the vicinity of points 1, 2, 3, and 4 may also allow the perception of fit to be improved.

23.3.2 Importance of Footbed Shape

Currently, footwear fit evaluations have been limited to dimensional effects in the medio-lateral sides of the foot (usage of foot widths and outlines) and only a few approaches, such as those of Luximon, Goonetilleke, and Tsui (2003a) and Leng and Du (2006), have considered the fit in all regions of the foot, including that of the plantar surface. A study conducted by Llana et al. (2002) with 146 tennis players found that the midfoot plantar region had the most discomfort (11.1%) compared to other areas of the body possibly as a result of incorrect arch support height or placement. Other researchers, such as Lee and Hong (2005) and Hong et al. (2005), have used plantar pressure distributions to improve footwear fit and comfort. Both plantar mid-foot shape and shoe shank shape affect the plantar pressure distribution (Alemány et al. 2003). High plantar pressure is related to pain and discomfort (Godfrey, Lawson, and Stewart 1967; Hodge, Bach, and Carter 1999) and hence the footbed or foot supporting surface plays an important role in improving comfort. The footbed, which is the reverse replica of the bottom shape of a shoe last, has many variables, such as heel height, heel seat length, wedge angle, shank shape, and toe spring (Adrian 1991) built into it, as shown in Figure 23.7.

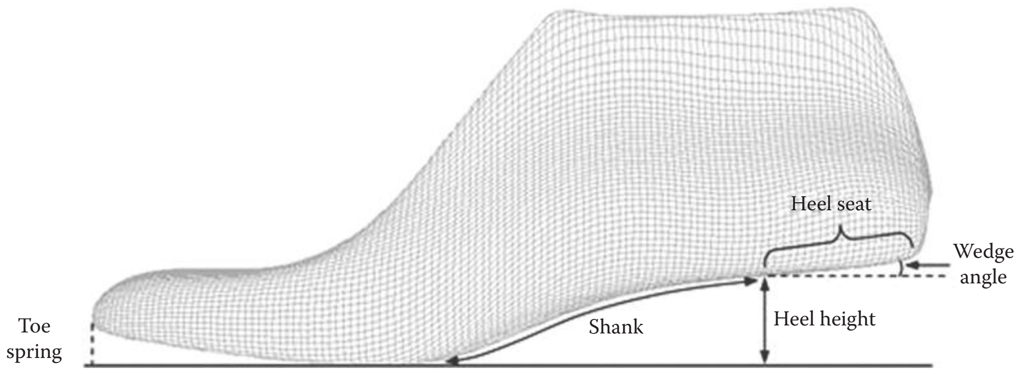


FIGURE 23.7 Shoe-last characteristics that determine the shoe-last bottom shape.

Snow and Williams (1994) found that when the shoe heel height changed from low heeled (1.91 cm) to high heeled (7.62 cm), the static forefoot loading increased from 39% to 57% of body weight, respectively. Other studies, such as Nyska et al. (1996), Mandato and Nester (1999), and McBride et al. (1991), have found that the forces at the first MPJ (Figure 23.1) in female participants when wearing high-heeled shoes was twice that of walking barefooted. Furthermore, when wearing higher heel heights, the pressures under the forefoot increase (Rodgers and Cavanagh 1989; Nyska et al. 1996) and the peak pressure shifts toward the first metatarsal and the hallux (Mandato and Nester 1999). Consequently, the foot shape and foot dimensions change depending on heel height (Kouchi and Tsutsumi 2000). Lee and Hong (2005) reported that, as a result of compensatory changes in the foot, footwear comfort significantly reduces with increases in heel height, but shoe inserts helped improve comfort. Similarly, others such as Hong et al. (2005) recommend the use of custom-made semi-rigid inserts over the midfoot and hindfoot areas to make high-heeled shoes more comfortable. Simply put, a higher contact area seems to alter the plantar pressure and helps to improve the perceived comfort. This notion is supported by the total contact cast (TCC) used by Hartsell et al. (2004) where they showed that a higher contact area inevitably reduces plantar pressure.

The contact area plays an important role in achieving the right pressures and the right fit. The suitability of the different footbed shapes can be checked with interface pressure analyses. However, this is a rather cumbersome and tedious process and is by no means the optimal way to check the suitability of any support shape. Instead, a device that can simulate different shapes and material properties will allow the effects of footbed shapes to be studied in depth so that the ideal shapes can be determined and tested. The profile assessment device (PAD, patent No: US 7,685,728, March 30. 2010) simulates any footbed shape in order to investigate the shape effects on a wearers' perceived feelings. The PAD is first pre-set to simulate any parameter on the bottom surface of a last (Figure 23.7) and then the perceived feel of that shape can be evaluated relatively easily. Figure 23.8 shows the profiles of two footbed shapes simulated on the PAD. One particular subject perceived

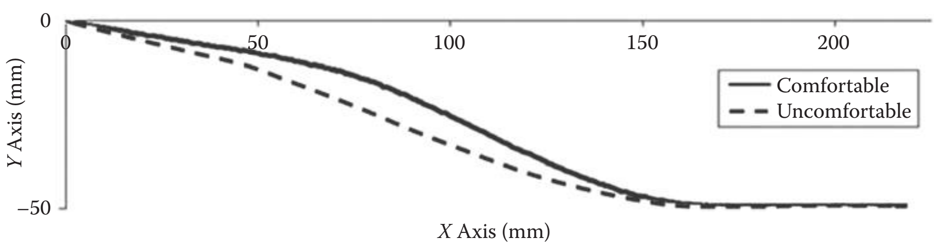


FIGURE 23.8 Two different footbed shapes simulated in PAD for 50 mm heel height (solid: comfortable footbed shape; dotted: uncomfortable footbed shape).

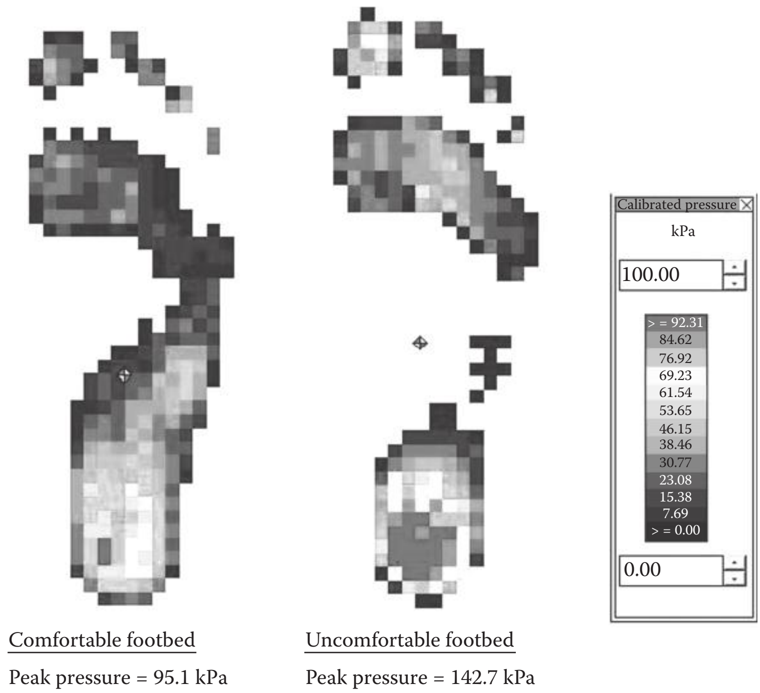


FIGURE 23.9 Plantar pressure measurements while standing on comfortable and uncomfortable footbed shapes simulated using PAD. (Refer to Figure 23.8 for the relevant footbed shapes.)

one of the shapes to be comfortable when standing on it, while the other shape was not comfortable. The plantar pressure patterns when standing on each of the two footbed shapes are shown in Figure 23.9. It is clearly seen that the comfortable footbed shape has a lower peak pressure and a higher contact area.

23.3.3 Modeling Foot Dorsal Shape

Even though foot measures of foot length, foot width, and ball girth are useful to map the shapes from a foot to a shoe last, they are insufficient to characterize the complex 3D foot shape (Luximon 2001). The foot shape can be acquired via digitization technologies such as with the use of laser scanners (Viavor 2007). However, the scanners tend to be quite expensive and thus cost-effective methods such as mathematical models to generate the foot shape with a few dimensions and/or profiles can greatly enhance the process of footwear design and development. Luximon (2001) modeled the 2D foot outline from 12 foot landmarks; the mean absolute positive error of that model was 1.69 mm and the mean absolute negative error was 0.93 mm. The profiles, whether they are the traditional foot outline or the side view outline, are important to obtain the boundaries of a last. There has been little attention paid to the side view outline, which is primarily governed by the dorsal shape of a foot (Xiong and Goonetilleke 2006, 2007), possibly because shoe laces can account for potential mismatches between the foot dorsal shape and the shoe upper.

For "closed" shoes such as boots, the dorsal shape of the foot is important in designing the shoe vamp or upper (Janisse 1992; Xing et al. 2000). This is an area where some shoe wearers have discomfort due to misfits between the vamp and the navicular area of the foot. Xiong and Goonetilleke (2006) modeled the 2D foot dorsal shape of 24 Hong Kong female participants when the subjects were standing on both feet. The data were analyzed by dividing the midfoot region into several strips of 1.2 mm thickness (i = 1, 2, 3… in Figure 23.10). The plot of strip height, H_i, vs. toe-to-strip

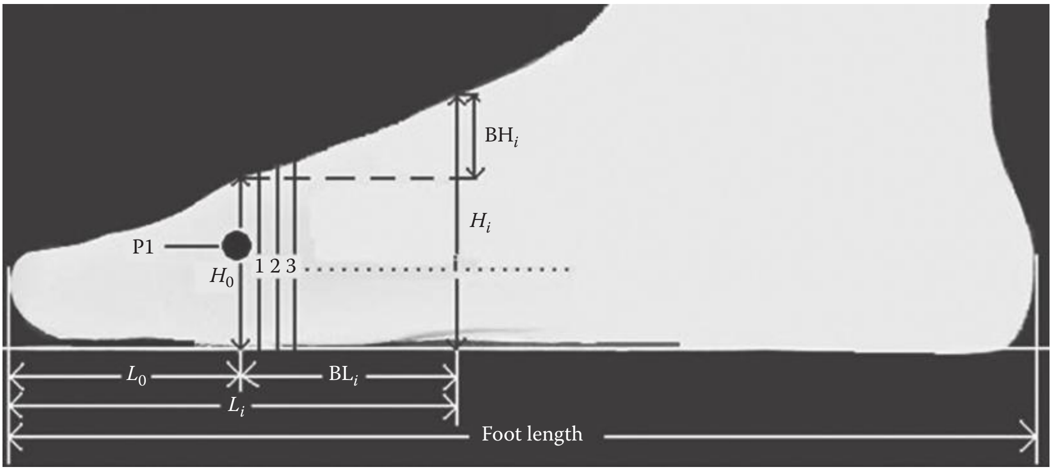


FIGURE 23.10 Foot dorsal heights in the midfoot region: P1 is the landmark on the most medial prominence of the first metatarsal-phalangeal joint (MPJ1); H_0 and L_0 are strip height (from the floor) and toe to strip distance at MPJ1; H_i and L_i are height and distance for ith strip.

distance, L_i, is shown in Figure 23.11. The curves of the different subjects appear to be parallel to each other in Figure 23.11. This pattern indicates that the starting height (H_0) and the starting position (L_0) of the MPJ1 are variable among the different participants. To account for these variations, the normalized variables, $\text{BH}_i = (H_i - H_0)$ and $\text{NBL}_i = (L_i - L_0)*100/\text{FL}$, were determined to develop a unified model across different foot sizes.

The least squares fit between BH and NBL (Figure 23.12) with zero intercept is shown below ($R^2 = 0.937$).

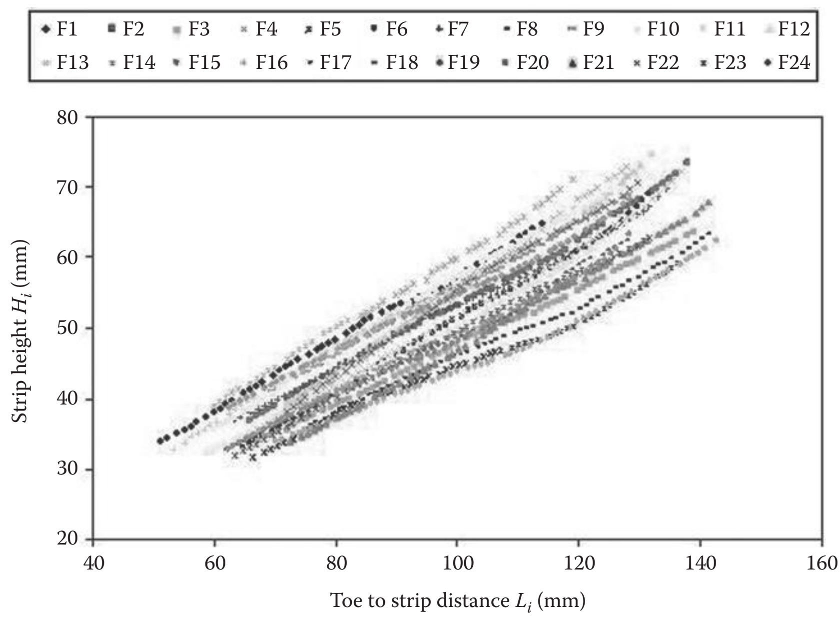


FIGURE 23.11 Strip height (H_i) vs. toe to strip distance (L_i) in the midfoot region excluding the toe areas (beyond the first metatarsal-phalangeal joints) for Hong Kong Chinese females denoted as F1, F2, F3…F24.

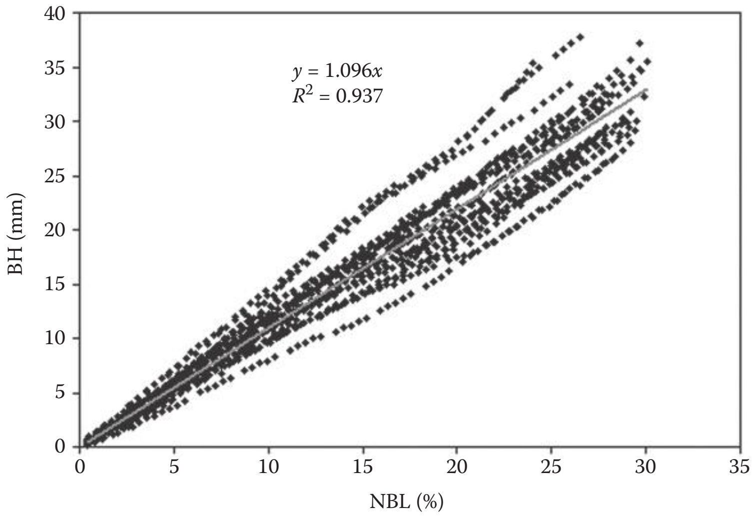


FIGURE 23.12 Scatter plot of BH (mm) and NBL (%) of all 24 Hong Kong Chinese females and the best fitted line through least squares method.

$$\text{BH (mm)} = 1.096 * \text{NBL (\%)}. \quad (23.5)$$

A further improvement to the aforementioned model (Xiong and Goonetilleke 2007) can be made by considering the foot height at 50% foot length (H_{50}) as an additional normalizing variable as ($H_{50} - H_0 - 3$) is directly proportional to the slope of each line. Thus, $\text{NBH}_i = \text{BH}_i/(H_{50} - H_0 - 3) = (H_i - H_0)/(H_{50} - H_0 - 3)$ was calculated and all the pooled data (NBH_i vs. NBL_i) can be fitted with a line having $R^2 = 0.984$. The linear relationship is given below.

$$\text{NBH (\%)} = 4.948 * \text{NBL (\%)}. \quad (23.6)$$

If the foot dimensions such as foot length, height (H_0), and length (L_0) at MPJ1 and or the height at 50% of foot length (H_{50}) are known, then the heights, H_i, of that person's foot at the different lengths, L_i, can be calculated using Equations 23.5 or 23.6.

23.4 CASE STUDY OF A BOOT

In order to illustrate how to integrate the aforementioned models to design footwear that fit better, a case study of a roller skate boot, as shown in Figure 23.13, is introduced.

FIGURE 23.13 An example of a child's roller skate. (Adapted from www.marcoskates.com Marco Skates Ltd. Hong Kong.)

Figure 23.14 illustrates the generalized flow chart of the steps to design footwear. In this case study, a random boot-last shape was adopted and can be modified using two different methodologies so that the resulting boot will have an improved fit. In the first method, the starting boot last was modified using standard shoe-last grading systems (Figure 23.14: Adjusted last shape 1). This procedure can be performed with footwear design CAD/CAM packages, such as FootWare™ from Vorum Research Corporation (www.vorum.com). In the second method, the last can be modified using the measured dimensions of the customer's foot (Figure 23.14: Adjusted last shape 2).

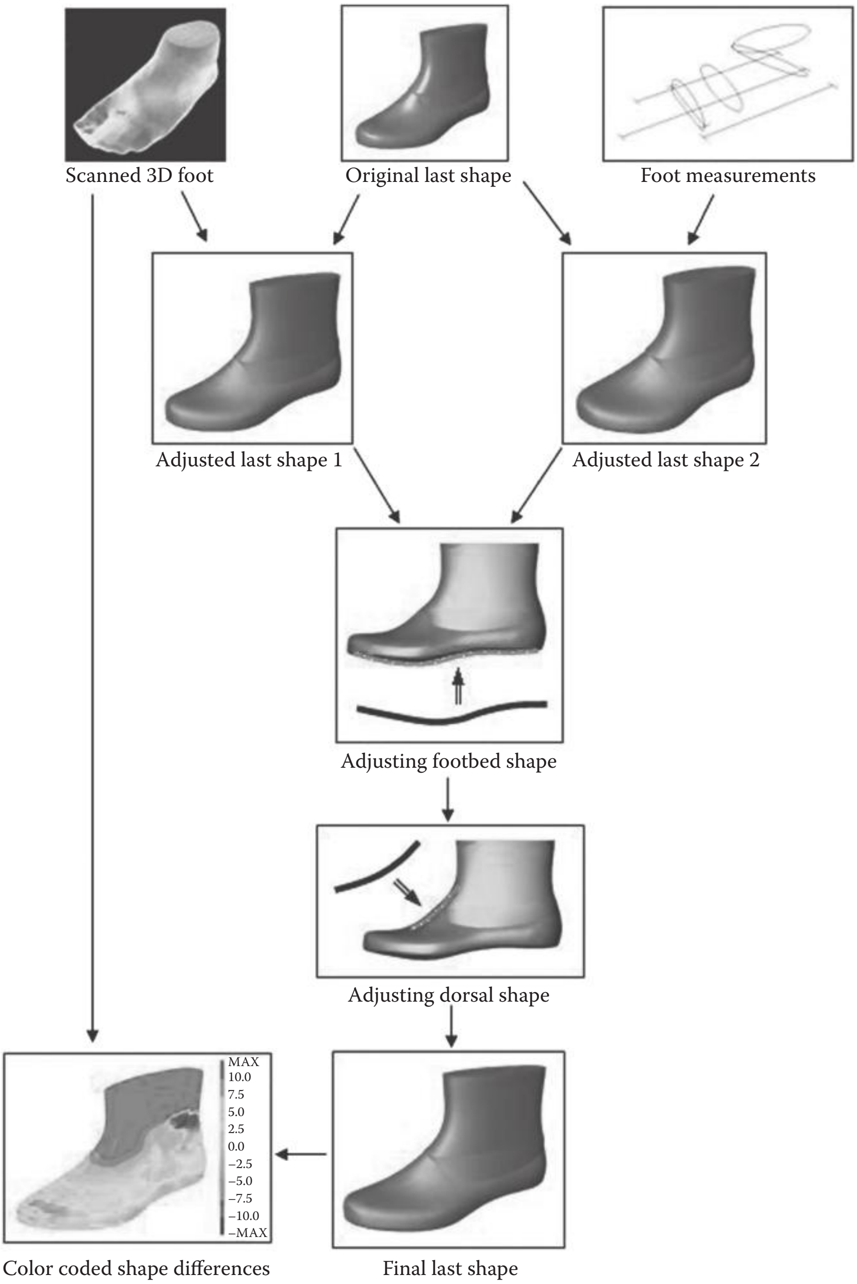


FIGURE 23.14 A structured approach to designing a boot last.

Once the adjusted last shape is obtained, the footbed shape can then be incorporated onto it. The PAD is used to determine the preferred shape. Using custom software or other CAD/CAM packages, the preferred shape can be built into the last. Thereafter, the dorsal region of the last is modified using one of the dorsal foot shape models (Equations 23.5 and 23.6) corresponding to the customer's foot dimensions. The fit of the resulting last can then be evaluated digitally by comparing the last shape and the customer's 3D foot shape. An example is shown using color coding in Figure 23.14.

To conclude, manufacturers lack or fail to use many models and techniques that can enhance the fit and comfort of footwear. This chapter is aimed at improving the understanding of the design and development of footwear so that more human factors and ergonomics researchers will be involved in this important process.

ACKNOWLEDGMENT

This work was made possible due to the numerous grants, especially HKUST 613607, 613406 and 613008 received from the Research Grants Council of Hong Kong and NSFC71001066 and 70971084 from the National Science Foundation of China.

REFERENCES

Adrian, K.C. 1991. *American Last Making: Procedures, Scale Comparisons, Sizing and Grading Information, Basic Shell Layout, Bottom Equipment Standards*. Arlington, MA: Shoe Trades Publishing Co.

Alemány, S., Nácher, B., Alcántara, E., González, J.C., and Sanchis, E. 2003. Morphological analysis of the lateral foot shape at different heel heights. In *ISB Technical Group on Footwear Biomechanics, 6th Symposium on Footwear Biomechanics*. Queenstown, NZ.

Au, Y.L., and Goonetilleke, R.S. 2005. Comfort characteristics of ladies' dress shoes. In *3rd Interdisciplinary World Congress on Mass Customization and Personalization*, 18–21 September, eds. F.T. Piller and M.M. Tseng, Hong Kong, CD-ROM. HKUST, Hong Kong.

Baba, K. 1975. Foot measurement for shoe construction with reference to the relationship between foot length, foot breadth, and ball girth. *Journal of Human Ergology* 3:149–56.

Bao, H.P., Soundar, P., and Yang, T. 1994. Integrated approach to design and manufacture of shoe lasts for orthopaedic use. *Computers & Industrial Engineering* 26:411–21.

Blais, F., Bisson, J.A., Williams, S., Robertson, N., Rozin, S., and Nelson, A. 2000. The shape grabber foot-scanner: A low cost high accuracy 3-D system for the acquisition of human feet. In *Three-Dimensional Image Capture and Applications III*, ed. B.D. Corner and J.H. Nurre, 178–86, *Proceedings of the SPIE*, Vol. 3958. SPIE press.

Bunch, R.P. 1988. Foot measurement strategies for fitting athletes. *Journal of Testing and Evaluation* 16 (4): 407–11.

Cavanagh, P.R. 1980. *The Running Shoe Book*. Mountain View, CA: Anderson World.

Chen, C.S. 1988. Developing a feature based knowledge system for CAD/CAM integration. *Computers and Industrial Engineering* 15:34–40.

Cheng, J.C.Y., Leung, S.S.F., Leung, A.K.L., Guo, X., Sher, A., and Mak, A.F.K. 1997. Change of foot size with weightbearing: A study of 2829 children 3 to 18 years of age. *Clinical Orthopaedics and Related Research* 342:123–31.

Cheskin, M.P. 1987. *The Complete Handbook of Athletic Footwear.* New York: Fairchild.

Chong, W.K.F., and Chan, P.P.C. 1992. *Consumer Buying Behaviour in Sports Footwear Industry*. Hong Kong: Business Research Centre, Hong Kong Baptist College.

Clarks Ltd. Training Dept. 1989. *Manual of Shoe Making*. Training Department Clarks, UK.

Feng, J.J. 2002. Footwear fit modeling and evaluation. MPhil thesis, Hong Kong University of Science & Technology.

Freedman, A., Huntington, E.C., Davis, G.C., Magee, R.B., Milstead, V.M., and Kirkpatrick, C.M. 1946. *Foot Dimensions of Soldiers. Third Partial Report Project NT-13*. Fort Knox: Armored Medical Research Laboratory.

Frey, C., Thompson, F., Smith, J., Sanders, M., and Horstman, H. 1993. American orthopaedic foot and ankle society women's shoe survey. *Foot Ankle* 14:78–81.

Gärtner, H., Lavoie, J.F., Vermette, E., and Houle, P.S. 1999. Multiple structured light system for the 3D-measurement of feet. In *Proceedings of Three-Dimensional Image Capture and Applications II (IS&T/SPIE) Conference.* San Jose, CA, January, vol. 3640, 104–14. SPIE press.

Godfrey, C.M., Lawson, G.A., and Stewart, W.A. 1967. A method for determination of pedal pressure changes during weight-bearing: Preliminary observations in normal and arthritic feet. *American Journal of Public Health* 78:1563–67.

Goonetilleke, R.S., Ho, E.C.F., and So, R.H.Y. 1997. Foot anthropometry in Hong Kong. In *Proceedings of the ASEAN 97 Conference*, 81–88. Malaysia: Kuala Lumpur, IEA Press.

Hartsell, H.D., Brand, R.A., Frantz, R.A., and Saltzman, C.L. 2004. The effects of total contact casting materials on plantar pressures. *Foot & Ankle International* 25 (2): 73–78.

Hawes, M.R., and Sovak, D. 1994. Quantitative morphology of the human foot in a north American population. *Ergonomics* 37 (7): 1213–26.

Hodge, M.C., Bach, T.M., and Carter, G.M. 1999. Orthotic management of plantar pressure and pain in rheumatoid arthritis. *Clinical Biomechanics* 14:567–75.

Hong, W.H., Lee, Y.H., Chen, H.C., Pei, Y.C., and Wu, C.Y. 2005. Influence of heel height and shoe insert on comfort perception and biomechanical performance of young female adults during walking. *Foot & Ankle International* 26:1042–48.

Janisse, D.J. 1992. The art and science of fitting shoes. *Foot and Ankle* 13 (5): 257–67.

Kos, L., and Duhovnik, J. 2002. A system for footwear fitting analysis. *International Design Conference*, 1187–92. Design Dubrovnik, Croatia, May 14–17.

Kouchi, M. 2003. Inter-generation differences in foot morphology: Aging or secular change? *Journal of Human Ergology* 32:23–48.

Kouchi, M., and Tsutsumi, E. 2000. 3D Foot shape and shoe heel height. *Anthropological Science* 108 (4): 331–43.

Lee, Y.H., and Hong, W.H. 2005. Effects of shoe inserts and heel height on foot pressure, impact force, and perceived comfort during walking. *Applied Ergonomics* 36:355–62.

Leng, J., and Du, R. 2006. A CAD approach for designing customized shoe last. *Computer Aided Design and Applications* 3 (1–4): 377–84.

Liu, W., Miller, J., Stefanyshyn, D., and Nigg, B.M. 1999. Accuracy and reliability of a technique for quantifying foot shape, dimensions and structural characteristics. *Ergonomics* 42 (2): 346–58.

Llana, S., Brizuela, G., Dura, J.V., and Garcia, A.C. 2002. A study of the discomfort associated with tennis shoes. *Journal of Sports Sciences* 20:671–79.

Luximon, A. 2001. Foot shape evaluation for footwear fitting. PhD thesis, Hong Kong University of Science and Technology.

Luximon, A., Goonetilleke, R.S., and Tsui, K.L. 2003a. Footwear fit categorization. In *The Customer Centric Enterprise. Advances in Mass Customization and Personalization*, eds. M. Tseng and F. Piller, 491–99. Berlin/Heidelberg/New York: Springer Verlag.

———. 2003b. Foot landmarking for footwear customization. *Ergonomics* 46 (4): 364–83.

Mandato, M.G., and Nester, E. 1999. The effects of increasing heel height on forefoot peak pressure. *Journal of the American Podiatric Medical Association* 89 (2): 75–80.

McBride, I.D., Wyss, U.P., Cooke, T.D.V., Chir, B., Murphy, L., Philips, J., and Olney, S.J. 1991. First metatarsophalangeal joint reaction forces during high-heel gait. *Foot Ankle* 11:282–88.

McEvoy, C. 1996. Comfort is job one. *Sporting Goods Business* 29 (9): S10.

Novotni, M., and Klein, R. 2001. Geometric 3D comparison – An application. *ECDL WS Generalized Documents.* ECDL 2001 September 8. Darmstadt, Germany.

Nyska, M., McCabe, C., Linge, K., and Klenerman, L. 1996. Plantar foot pressure during treadmill walking with high-heel and low-heel shoes. *Foot and Ankle International* 17 (11): 662–66.

Osada, R., Funkhouser, T., Chazelle, B., and Dobkin, D. 2001. Matching 3D models with shape distributions. In *Proceedings of the International Conference on Shape Modeling and Applications*, 154–66. SMI 2001, May 7–11, Genova, Italy. Los Alamitos, CA: IEEE Computer Society.

Pheasant, S. 1988. *Bodyspace: Anthropometry, Ergonomics and Design*. New York, Philadelphia, London: Taylor & Francis.

Piller, F.T. 2002. The market for customized footwear in Europe: Market demand and consumer preferences. Euroshoe Project report (www.euroshoe.net).

Rodgers, M.M., and Cavanagh, P.R. 1989. Pressure distribution in Morton's foot structure. *Medicine and Science in Sports and Exercise* 21:23–33.

Roebuck, J.A. 1995. *Anthropometric Methods: Designing to Fit the Human Body*. Santa Monica, CA: Human Factors and Ergonomics Society.

Rossi, W.A. 1983. The high incidence of mismatched feet in population. *Foot and Ankle* 4:105–12.

Rossi, W.A., and Tennant, R. 2000. *Professional Shoe Fitting.* New York: Pedorthic Footwear Association with acknowledgement to the National Shoe Retailers Association.

Rys, M., and Konz, S. 1989. Adult foot dimensions. In *Advances in Industrial Ergonomics and Safety I*, ed. A. Mital, 189–93. London: Taylor & Francis.

Shrout, P.E., and Fleiss, J.L. 1979. Intraclass correlations: Use in assessing operator reliability. *Psychological Bulletin* 86 (2): 420–28.

Snow, R.E., and Williams, K.R. 1994. High heeled shoes: Their effect on center of mass position, posture, three-dimensional kinematics, rearfoot motion, and ground reaction forces. *Archives of Physical Medicine and Rehabilitation* 75:568–76.

Treleaven, P. 2004. Sizing us up. *IEEE Spectrum Archive* 41 (4): 28–31.

Venkatappaiah, B. 1997. *Introduction to the Modern Footwear Technology*. Chennai, India: B. Sita.

Viavor. 2007. Shoe fitting viavor technology, http://www.viavor.com/en/fitting/technology.php (accessed September 22, 2007).

Witana, C.P., Goonetilleke, R.S., and Feng, J. 2004. Dimensional differences for evaluating the quality of footwear fit. *Ergonomics* 47 (12): 1301–17.

Witana, C.P., Xiong, S., Zhao, J., and Goonetilleke, R.S. 2006. Foot measurements from three-dimensional scans: A comparison and evaluation of different methods. *International Journal of Industrial Ergonomics* 36 (9): 789–807.

Wunderlich, R.E., and Cavanagh, P.R. 2001. Gender differences in adult foot shape: Implications for shoe design. *Medicine & Science in Sports & Exercise* 33 (4): 605–11.

Xing, D.H., Deng, Q.M., Ling, S.L., Chen, W.L., and Shen, D.L. 2000. *Handbook of Chinese Shoe Making: Design, Technique and Equipment*. Beijing: Press of Chemical Industry (In Chinese).

Xiong, S., and Goonetilleke, R.S. 2006. Midfoot shape for the design of ladies shoes. In *Conference on Biomedical Engineering, BME2006* (September 21–23) 158–60. Hong Kong: Hong Kong Productivity Council.

———. 2007. Can we do away with those cumbersome shoe laces? In *8th Pan-Pacific Conference on Occupational Ergonomics (PPCOE, 2007)*. October 17–19, Bangkok, Thailand, CD-ROM.

24 Virtual Reality in Consumer Product Design: Methods and Applications

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CONTENTS

24.1 INTRODUCTION

Users of consumer products currently benefit from the latest technology. Examples of such products include household appliances, entertainment-oriented products, automobile features, and communication devices. These technologies have had a large impact on user lifestyles, some of which have replaced manual labor while others have totally transformed social relationships. The current generation of consumers is extremely technologically knowledgeable and demanding of newer devices, expecting a combination of functions while aesthetically appealing. For example, a Smartphone is not only a source of communication, but also an entertainment media center, a computer with internet functions, and a camera/video recorder, etc. Consumers not only want a device to perform a variety of tasks, but require them to have improved functionality and usability at lower costs (Shackel 1991).

In this chapter, we consider usability as a broad concept, which involves both the objective and subjective usability attributes of electronic consumer products. The objective usability attributes, used frequently to evaluate the usability of consumer products, include: effectiveness, learnability, flexibility, understandability, memorability, and reliability. The subjective usability attributes refer, for example, to the product's attractiveness, which affects the positive attitude toward the product.

Since the 1980s, many companies have become more conscious of the value of usability, as a tool to gain strength in an increasingly competitive marketplace. Therefore, companies have invested deeply in usability laboratories for the testing of their products (Dillon 1988). However, laboratory studies have been shown to be ineffective in discovering usability problems that can occur in real-world usage because laboratory tests are based on simulations of consumer product usage. This can constitute a problem for usability testing since most of the simulations may lack accuracy and richness in the exact reproduction of the real situation of use. So, a move toward the development of usability studies in an ecological perspective has emerged, sustained by some researchers claiming that usability can only be assessed in the field (e.g., Bailey, Knox, and Lynch 1988).

Nevertheless, in both laboratory and field approaches, a number of problems have emerged that can limit the accuracy of the usability tests. In the field applications, the main problems can be related to the difficulties in the manipulation and control of some of the variables due to possible changes in the real context. These kinds of problems can be more easily addressed in experimental laboratories where the variables can be controlled and measured with greater accuracy. However, within the laboratories, the infrastructural requirements and financial costs can be high, translating to higher product cost. Regardless of whether field or laboratory testing is used, ethical and user safety issues should always be addressed.

One way to conciliate the advantages of the field and laboratory approaches is by using virtual reality (VR), which allows the user to interact with a simulated product while immersed in a context that, despite being synthetic, could be similar to the real-world situation and, at the same time, allows the research to have full control of the variables and safety aspects. Besides this advantage, VR can be easily included in a participatory design methodology because of its effectiveness in the display of design solutions (Reich et al. 1996). The use of VR in product development has been tested in several application areas, such as the design of roads, medical products, and workplace layouts (e.g., Davies 2004; Dinka and Lundberg 2006; Kensing and Blomberg 1998; Heldal 2007; Mogensen and Shapiro 1998; Reich et al. 1996; Schuler and Namioka 1993). Another important advantage of VR is its ability to reduce the number of physical prototypes by using virtual prototypes (VP), which will decrease the costs and time in the development of new solutions.

In this context, this chapter, directed to human factor specialists, designers, and/or researchers, provides an overview of the methods and applications of VR technology applied to consumer product design. VR concepts and equipment are explained in order to give the basic information necessary to understand their advantages and integration in a user-centered design (UCD) perspective. In the last part of the chapter, some examples of how VR works in technological consumer product design are presented.

24.2 VIRTUAL REALITY CONCEPTS

24.2.1 What is Virtual Reality?

In a very broad sense, VR is a way of transporting a person to a reality in which they are not physically present but seems like they are there. Of course, any form of simple media (e.g., a text) or pictorial representation (e.g., a painting) can have a similar feeling in which the reader or viewer is abstracted from familiar surroundings to those within the story or painting.

Considering a technological VR continuum, in the other extreme of a text or a painting, we can devise the "ultimate display" proposed by Sutherland (1965) in his own words as "a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal."

According to the official encyclopedic definition, virtual reality is "the use of computer modeling and simulation that enables a person to interact with an artificial three-dimensional (3D) visual or other sensory environment. VR applications immerse the user in a computer-generated environment that simulates reality through the use of interactive devices, which send and receive information and are worn as goggles, headsets, gloves, or body suits. In a typical VR format, a user wearing a helmet with a stereoscopic screen views animated images of a simulated environment" (Virtual Reality 2010).

24.2.2 Fundamental Concepts in Virtual Reality

The concepts of immersion, presence, interaction, and involvement are important in understanding the physical and psychological experience of users in VR. The definition and meaning of each of these concepts can differ with each author.

According to Gutiérrez, Vexo, and Thalmann (2008), fundamental concepts are immersion and presence. They classified the kind of immersion based on the physical configuration of a VR user interface: fully immersive (using head-mounted display), semi-immersive (large projection screens), or non-immersive (desktop-based VR). The physical level of immersion is dependent on how much the user can perceive of the real world (Gutiérrez, Vexo, and Thalmann 2008). Thus, the lower the perception (see, hear, touch) of the real world, the greater the classification of immersion in VR.

Presence is a subjective concept associated with psychological aspects of the user relationship to the sense of being in the virtual environment (VE). When the brain processes and understands multimodal stimulations (image, sound, etc.) as coherent environments where it is possible to act and interact, there is presence. Thus, presence is achieved when the user is conscious, deliberately or not, of being in a VE (Gutiérrez, Vexo, and Thalmann 2008).

Witmer and Singer (1998) developed a questionnaire to evaluate presence, and define it as the subjective experience of being in one place or environment, even when one is physically situated in another. Presence refers to experiencing the VE rather than the actual physical locale. The necessary conditions for experiencing it are involvement and immersion.

According to Witmer and Singer (1998), involvement is "the psychological state experienced as consequence of focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities and events." Immersion is the "psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli" (Witmer and Singer 1998, 227). Even though a video game played on a standard home television is in a non-immersive environment, nonetheless, it may lead to high levels of involvement. Involvement is related to concentration on the VE, thus any factor distracting the user can affect the involvement.

Immersion is dependent on isolation from the real world provided by a VR interface and with the quality of interaction with tasks and the environment in VR. In a VR context, interaction is connected with communication between the user and the VR system. The capacity of detecting user motions and actions (user inputs) and refreshing the VE, according those inputs defines interaction.

According to Witmer and Singer (1998), though the factors underlying involvement and immersion may differ, the levels of each one experienced in the VE are interdependent. That is, increasing the level of involvement may lead users to experience more immersion in an immersive environment and vice versa. Presence experience is a conjugation of factors affecting both involvement and immersion.

24.3 VIRTUAL REALITY TECHNOLOGY

Considering the computer system, Burdea and Coiffet (2003) divide VR technology into input devices (e.g., trackers, navigation, and gesture interfaces) and output devices (e.g., graphics, sound, and haptic displays). Thus, from the human point of view, input devices are activated from user action (e.g., head motion, body motion, and voice) and output devices activate human senses (e.g., visual, aural, tactile, proprioceptive). We will define VR technology from these two flows of information between human and computer. The increase of inputs and outputs will make the system more immersive. According to Steuer (1992), immersion is also defined by its breadth (e.g., multiple sensory modalities stimulated) and depth (e.g., resolution with respect to vision). The greater the breadth and depth, the more immersive is VR. Thus, in VR there is no clear separation between immersive or not immersive. Nonetheless, for practical reasons, we will use the Gutiérrez, Vexo, and Thalmann (2008) classification of non-immersive, semi-immersive, and fully immersive.

In a non-immersive VR, desktop computers and an LCD monitor are often used. Sometimes, users also wear 3D glasses to enhance visual depth and create stereoscopic effects. Any input device can be used, like a joystick, a trackball, or a data glove. Biocca and Delaney (1995) refer to these systems as window systems since the computer screen provides a window or portal onto an interactive, 3D, virtual world.

In a semi-immersive VR, users are in an enclosed room where they are surrounded by large screens that project the VE. Thus, it is possible to have a large field of view (FOV) and to use 3D glasses. CAVE (Audio-Visual Experience Automatic Virtual Environment) systems are examples of a semi-immersive system.

Fully immersive VR (Figure 24.1) corresponds to most of the images of VR represented in social communication media. The objective is to completely isolate the user from the real world. An example of a fully immersive display is the stereoscopic head-mounted display (HMD) (Figure 24.2).

FIGURE 24.1 Image of a VR setting. Subject using HMD and a data glove, with image of VE behind him retroprojected.

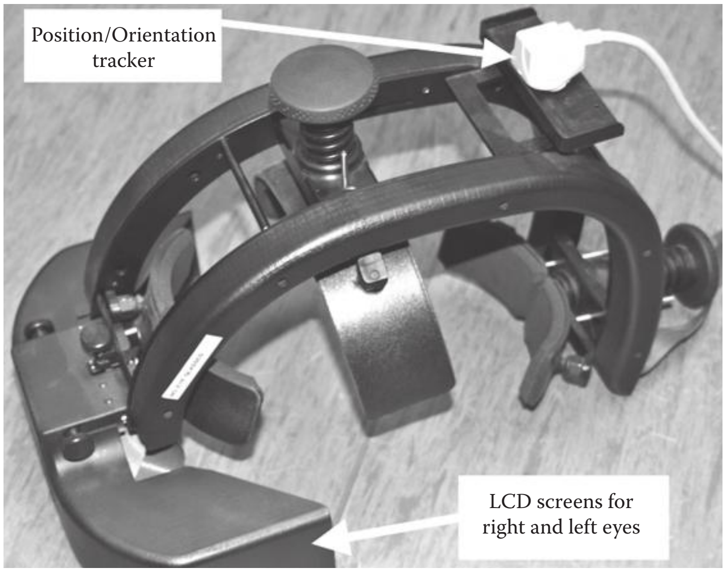


FIGURE 24.2 A HMD with a magnetic position/orientation tracker.

In order to allow a good interactivity of a VR system, it is necessary to use interface devices designed to input a user's command into the computer and provide feedback from the simulation to the user through output devices.

24.3.1 Input Devices

Three-dimensional position trackers used in VR allow measuring of the real-time change in a 3D object position and orientation (Burdea and Coiffet 2003), for the purpose of view control, locomotion, and object manipulation. In a VR system, head tracking is crucial for achieving immersion sensation since its correct tracking depends on the correct actualization of the viewer point of view (perspective). If one turns their head from one side to another, visualization of the VE must be actualized in real time for the correct perspective. Also, information from the head tracker can also be used to compute the correct source of 3D sound.

Trackers can also be applied to data gloves and/or data suits to record the movements/positions of other body parts. Body parts tracked in 3D reality can also be presented in real-time in the avatar in VR.

Several technologies for trackers are available: mechanical, magnetic, optical, and ultrasonic. The evaluation of each of these technologies should be made using a set of criteria (Meyer, Applewithe, and Biocca 1992), such as accuracy/precision and resolution (how accurate is the information given about the location and minimal changes detected by the system), correspondence/speed of response (the degree of speed of the resulting data and the interval with which they are received), robustness (the capacity to operate in any environment), registration (the correspondence between the position reported and the current position), and sociability (the operating range and the ability to track multiple objects).

Mechanical trackers consist of a serial or parallel kinematic structure composed of links interconnected using sensorized joints (Burdea and Coiffet 2003). Mechanical trackers compute position change, physically connecting the remote object to a reference point. Since the coexistence of two sensors would mechanically interfere with other tracking devices, the hands and head are tracked separately. Nonetheless, these sensors are very accurate and can be combined with mechanisms for force feedback. Despite their accuracy, these sensors have long delays and are quite intrusive.

A magnetic tracker (cf. Figure 24.2) is a position measurement device that operates by detecting changes in a magnetic field between a sender and a receiver. The transmitter produces a magnetic field, and the receiver sensor measures induced currents. This reading calculates the relative position and orientation. Magnetic sensors are the most common and are easy to find on the market. They are more adequate in covering large areas than the mechanical tracker, but are subject to distortion field and electromagnetic interference (e.g., proximity of metal).

Optical trackers use video cameras (sensors) to detect the light emitted by an infrared light (transmitters). These devices, compared with the magnetic ones, can work over a wide area. However, these systems suffer from the problem of occlusion/obstruction between the camera and the infrared light (e.g., when a sensor is hidden by an object or part of the body of the participant). Nonetheless, increasing the number of sensors and transmitters can reduce the probability of occlusions and obstructions.

The ultrasonic trackers use microphones and transmitters to calculate via triangulation the distance between the source and the receiver. They are cheap and light but are subject to interference from echoes and sounds and, therefore, have low fidelity.

The inertial trackers use accelerometers and gyroscopes to measure body motion. Inertial trackers offer several advantages such as sourceless operation with unlimited range, no line of sight constraints, and a reduced latency. However, the drawback of inertial sensors is the accumulation of position errors related to gyroscope bias through time.

Besides the information that trackers give about position and orientation in 3D space, the VR systems have interfaces that allow the user to navigate in the VE. For example, the user is not restricted to a confined space when wearing the VR equipment, but to an unlimited simulated space. Tracker-based navigation interfaces are also available, which integrated within a structure with user-programmable pushbuttons became simultaneously navigation and manipulation interfaces (e.g., trackballs and sensing gloves). A sensing glove allows measuring of the position of the fingers in order to enable gesture-recognition-based interaction with objects in the VE.

24.3.2 Output Devices

In response to user input, VR equipment gives a sensorial feedback that can use graphical, sound, haptic, olfactive, and taste output devices. Even though feedback for all sensorial modalities (cf. Gutiérrez, Vexo, and Thalmann 2008) is possible, here only visual, haptic, and auditive feedback devices will be analyzed.

24.3.2.1 Visual Feedback

Because of the importance of vision, VR display devices should ensure proper viewing of the VE and its details. Depending on the kind of task studied, participants should receive adequate resolution of visual stimuli (colors, brightness, and adequate representation of motion). In some tasks, like those involving manipulation of objects near the subject, stereoscopic vision (3D-vision) could increase the user performance. Visual data should be updated continuously and instantaneously to reflect the natural movement of the user in the virtual world.

The most common visual devices are VR HMDs, "Shutter Glasses," "Passive Glasses/Through the Window," and CAVE.

24.3.2.1.1 Head-Mounted Displays

The HMD was originally created by Ivan Sutherland in 1968 and was nicknamed the "Sword of Damocles." It was a large contraption suspended from the ceiling, which could follow the head position of the user and provide the corresponding viewing angle (Pimentel and Teixeira 1994). Thanks to technological development, other less intrusive and more comfortable systems emerged. The "NASA Ames HMD" was comparatively lighter and its tracking was performed by magnetic sensors rather than mechanical sensors. The display was made up of small liquid crystal screens with 620×620 pixel resolution, 16 gray shades, and LEEP lenses that allowed 120° of FOV.

Because the HMD can be stereoscopic, it allows a greater sense of depth. For such displays the following aspects should be considered: distance between the pupils of the eyes, the difference between the angles of vision of each eye, and possible distortions caused by the hardware. HMD has a number of resolutions and FOV. A lower FOV may cause tunnel vision and, as a consequence, may decrease the immersion. By contrast, a larger FOV may involve a "spread" of pixels, which results in a reduction of the resolution and some distortion. Conflicts with visual cues cannot be ignored. In fact, participants will use a fixed distance for accommodations when the viewed images require different depths of view.

24.3.2.1.2 Shutter Glasses

Shutter glasses are designed to provide a 3D vision of the VE. Each lens is replaced by an electronic shutter synchronized with displayed images on screens or CAVE. Each lens alternately becomes opaque or transparent. Information about which image is being displayed and which lens should become opaque are sent to the glasses.

24.3.2.1.3 Passive Glasses

The techniques known as passive glasses are also known as "Through the Window." This designation encompasses a number of systems that have only one screen but can still display 3D images through different techniques.

The passive glasses are characterized by the display of images with different perspectives in each eye that are encoded with both color and light polarization. This is achieved through lenses containing filters that select which images are to be displayed in each eye.

Some of these devices make use of stereoscopic images (anaglyphs) printed in different colors with red and green filters that convey the sense of depth. To view these images, special glasses with one red lens and one green lens must be used. Thus, for each lens, the images in the color corresponding to the lens must be used to produce different views in each eye. Other devices use the lenses with polarized filters. The major advantage associated with this technique compared with HMD is the possibility of several users simultaneously viewing the same display and obtaining a stereoscopic vision. Even if the perspective is not correct for all, it still gives a good sense of depth.

24.3.2.1.4 CAVE Automatic Virtual Environment

The system called CAVE is a cube whose faces are retro projected screens with images of the VE, which surround the user. Each of these faces displays an image of the VE in the correct perspective in relation to the position of the user. This means that each face of the cube needs to be redesigned whenever the user moves. CAVE is not able to provide the same accuracy with the correct perspective when more than one person is in the cube.

24.3.2.1.5 Comparison

Sadasivan et al. (2006) compared the use of Window-VR and HMD for inspection tasks performed in VEs using a 6-degrees of freedom (DOF) mouse and reported no significant differences between the two display systems. However, each system had particular advantages. HMD was considered because it offered a greater degree of immersion and interaction with the environment and was considerably easier and more convenient. Window-VR was considered because it offered greater ease in the manipulation of the environment for recognizing defects.

24.3.2.2 Haptic Feedback

The use of tactile feedback is still poorly supported in common systems. According to Hirose (1992), the simulated touch can be achieved in various forms: pins/connectors, mechanical transmissions activated by solenoids and/or piezoelectric crystal (a modification of the electric fields causes the expansion and concentration), alloy materials with shape memory technology, voice coils of high-frequency vibrations transmit low amplitudes in the skin, various pneumatic systems (air-jets, air-rings, bladders), and heat pumps.

Unlike what happens with the tactile sense, kinesthetic interfaces are well developed. Technologies used to give the force feedback are electromagnetic motors that produce a torque in two magnetic fields that vary over time, hydraulic systems where a pressurized fluid is distributed among the components, and pneumatic systems using pressurized gases.

24.3.2.3 Auditive Feedback

In VR, the sound is important to maintain consistency with the real world (e.g., objects usually produce sounds) and to give clues containing additional or redundant information that cannot be transmitted visually. Sounds can also indicate the presence in the VE of certain elements. Auditory cues can help lighten the load of the visual scene.

The auditory cues should be located in a specific position in the VE (3D sounds). Normally, when using headphones the sound appears to be inside the head. Thus, to be able to determine the source of sound in the VE, a person will need a program to model the propagation of sound. Basically, the technique used to achieve this effect involves the modeling of the signal at different times of arrival and amplitude to the left and right ears, giving the sound a coarse horizontal direction. To go further and give the sound a more enhanced feeling, it will be necessary to model the distortion to the signal crossing the pinna (ear). However, because this distortion is different for each person, individual modeling is needed (Wenzel 1992).

Other factors such as the reverberation of sound and synchronization with visual cues should also be considered. This latter issue can create problems for hardware because various components are used for each of these aspects, which may have different processing speeds. To manage the synchronization of the sound and the image, a script for the sound similar to that used in animation, needs to be created (Takala and Hahn 1992).

Some studies specifically about sound in VR (Loomis, Blascovich, and Beall 1999; Loomis, Hebert, and Cicinelli 1990; Zahorik 1997, 2002) have proposed some strategies to present the sound properly in VEs (e.g., identifying the location in space, a virtual speaker in the environment, the sound/noise environment).

24.4 VIRTUAL REALITY APPLICATIONS

Two types of different approaches are referred to when VR applications are mentioned. Usually, approaches can refer to contexts (e.g., military, health, transport, manufacturing, entertainment, cultural heritage) or types of applications (e.g., virtual prototyping, training, research, teleoperation). Thus, in the same application, there may be two different contexts in use simultaneously; e.g., in health, an application that targets the surgical training of a particular technique such as endoscopic surgery (Székely et al. 2000) and in the same context uses VR as real-time support for neurosurgery in a kind of teleoperation application (Warfield et al. 2000).

24.4.1 Training

An excellent example of the application of VR is driver training (Bayarri, Fernandez, and Perez 1996; Kallmann et al. 2003; Kuhl et al. 1995) and aircraft simulators (Hüsgen, Lulevaa, and Klingaufa 2006). Also, in the military context, VR is used for training soldiers (Page and Smith 1998). There are numerous applications for training fighter pilots (Moroney and Moroney 1991; Mueller 1995; Pisanich and Heers 1995), radar operators, sailors who operate submarines, and others.

Several studies have used immersive VR to investigate issues related to education and training (Albright and Graf 1992; Auld and Pantelidis 1994; Emerson and Revere 1999; Neale et al. 1999; Roussos and Gillingham 1998; Roussos et al. 1999; Salzman et al. 1999). Many institutions are already applying VR in education to provide services to different types of students (Crosier, Cobb, and Wilson 2000; Jackson and Fagan 2000; Johnson and Rickel 1997).

One area where VR is also applied is in teaching/training in medical fields (Riva and Mantovani 1999), allowing students to make their first surgeries without putting a patient's life at risk (Machado 2003; Matern et al. 2005), or physicians to practice new surgical techniques (Downes et al. 1998; Satava 1993; Tendick et al. 2000). There are also applications for the training of physicians concerning primary care and emergencies (Chi et al. 1997; Stansfield, Shawver, and Sobel 1998). Immersive VR has also been widely used for training in areas such as mechanical engineering (Caudell and Mizell 1992; Feiner, Macintyre, and Seligmann 1993; Loftin 1993), for speakers before large audiences (Pertaub, Slater, and Barker 2002), and for leaders in team leadership.

24.4.2 Medical Treatment

In the therapy context, VR has made progress particularly in treating people with phobias (Rizzo, Wiederhold, and Buckwalter 1998), e.g., public speaking (Lee et al. 2002). Some researchers have used VR to model scenarios with virtual patients to serve as training for therapists. VR has also been used to develop therapeutic tools (Riva, Wiederhold, and Molinari 1998; Rothbaum et al. 1995; Vincelli 1999), such as the treatment of fear of heights (Coelho et al. 2006, 2009) and fear of flying (Rothbaum et al. 2000). In addition, VR has been used in the diagnosis and treatment of several developmental problems, such as learning and behavioral disorders involving problems with concentration/attention, hyperactivity, and autism (Cho et al. 2002; Glantz, Rizzo, and Graap 2003; Krijn et al. 2004; Rizzo et al. 2000, 2004).

24.4.3 Ergonomics

In ergonomics, VR has been used to enhance the quality not only of the worker's life, but that of the products, the environment, the systems, and the employee training and education (Grave et al. 2001). Chryssolouris et al. (2000) used methods based on VR to check factors related to human performance in the task of the assembly of components. In this study, ergonomic models were embedded in a virtual immersive environment to conduct an ergonomic analysis of the work situation. Grave et al. (2001) developed a VR system for training operators on assembly lines of electric cables for the automotive industry.

Whitman et al. (2004) compared the results obtained by carrying out a task of the handling and transportation of volumes (palletizing task) in the real world and the virtual world to understand whether VR is suitable for use in an ergonomic analysis. The results obtained by comparing the movements of the torso showed that VR can be compared to a real situation if the evaluations are restricted to the range and movements measurement, but without measuring velocity and accelerations.

24.4.4 Architecture and Wayfinding

In the area of architecture, VR has been applied to allow interaction (display, scroll, and handling) in virtual spaces, indoors or outdoors, with different levels of realism. In these spaces, users can move freely and, in some cases, make modifications (e.g., change color environment, furniture placement, and lighting).

The study of navigation and orientation has proven to be the most successful application in this area (Airey, Rohlf, and Brooks 1990; Brooks 1986). One of the objectives of its use may be to evaluate the quality of wayfinding (Raubal and Egenhofer 1998; Raubal 2001) or behavior during the evacuation of buildings throughout emergency situations (Gamberini and Spagnolli 2003; Shendarkar et al. 2006). However, the level of exploitation of the VR spaces still seems to be rather limited, especially with regard to estimating the distance (ability of the user to calculate accurately the distance), which may be critical for some tasks. The literature reveals that participants are less able to estimate distances in a VE than in the real world with about 41%–72% of the actual distance in the VR and with 87%–91% in the real world (Witmer and Sadowski 1998). According to Witmer and Sadowski (1998), real-world estimates average around 75% of the correct distance (between 3 and 33 m) and in the VE the average estimate is about 50%. Witmer and Sadowski (1998) also show that the estimation is more accurate in cases of non-visually guided locomotion when the participant is asked to view the object first and afterwards walk in its direction without any visual guidance. This implies an estimation error of between 2% and 8% when viewing distances up to 22 m.

A task for which they found clear advantages in the use of VR was spatial orientation. Darken and Banker (1998) conducted a study to determine whether VR could serve as a tool to familiarize people with unknown environments. Three groups of participants with different levels of knowledge explored an environment in three conditions: studying a map, exploring the real environment with the map, and using a VE to study the map.

The spatial cognition implies the combination of variables such as piloting (use of environmental stimuli or cues as reference points or landmarks) and path integration (continuous updating of position based on movement in order to determine the position in each moment). With immersive VR it is possible to manipulate one of these variables by keeping the other controlled or by combining them (Chance et al. 1998; Klatzky et al. 1998). Other aspects of spatial cognition that can be improved by the use of VR are cognitive mapping and spatial memory (Wilson, Tlauka, and Wildbur 1999).

24.5 TECHNICAL LIMITATIONS AND SIDE EFFECTS OF VIRTUAL REALITY

VR is not free of problems and limitations. One important consideration when making the decision about using VR is the sense of immersion offered by the VR system. As pointed out by Bochenek and Ragusa (1998), it is important to select an appropriate VR system because aspects such as the sense of immersion play an important role in the design activities. Semi-immersive VR systems (e.g., desktop VR or projection VR) are relatively easy to use and affordable, but the immersion degree provided could be low (e.g., Morar and Macredie 2004; Wang and Li 2004). On the contrary, more immersive VR systems (e.g., HMD or CAVE), which can generate a high sense of immersion, are expensive and may place greater space requirements (e.g., CAVE). Thus, they are almost always used by large enterprises (Fairén, Brunet, and Techmann 2004; Hoffmann, Stefani, and Patel 2006). CAVE, in particularly, is a powerful visualization tool for collaborative applications that, despite offering the possibility to interact with the VE and the virtual objects with a good freedom, suffer some limitations regarding issues such as haptic and tactile feedbacks.

Although VR has many advantages for electronic consumer product development, there are also some disadvantages of which the VR practitioner should be aware. These disadvantages are not really directly associated with the modeling and analysis, but rather with the expectations associated with human–VE interaction in VR-based projects.

The lack of structured evaluations about VR effects lead to speculative opinions, namely, in reports made by journalists in the media, most of them associated with potential negative effects. Some studies focus on the social and psychological effects of VR use. Others focus on the physical or physiological effects, such as cyber sickness. Some examples include participants' efforts to re-adjust themselves to the real world after spending some time in the VE (Sherman cited by Nichols and Patel 2002) and addiction (Arthur 1992). However, more credible empirical studies highlight that participants may experience cyber sickness as a result of VR use. The justification for this problem is normally associated with the technology used, namely, poorly tracked systems with slow response and noise in the tracking system, which can cause nausea because of the mismatch between visual and proprioceptive or vestibular cues (e.g., Bolas 1994; Biocca 1992). Other affects are related to intrusiveness, discomfort, and awkwardness associated with features such as shape, weight, and adjustability of some devices (e.g., HMD, haptic devices). New solutions being developed by the manufacturers may solve these problems soon. It is also important to say that the positive aspects of VR, such as improved visualization performance, motivation, and enjoyment, may compensate for the negative effects experienced by the users.

In the near future, the HMD might be replaced by true 3D rendering methods such as volume holography and retinal displays that will make interaction with a VE more natural and comfortable. Also, the current computer-user interfaces are bulky and uncomfortable to wear, making them less useful during user interaction. Wireless solutions may turn out to be the next generation of VR interfaces.

24.6 CONTRIBUTION OF VIRTUAL REALITY TO THE USER-CENTERED DESIGN PROCESS

As stated before in this chapter, VR has been successfully used for diverse purposes, but its use for consumer product design, particularly the adoption of a UCD approach, has not yet been put into common use. Nonetheless, as stated by Davies (2004), VR environments, or VEs can be used for everything in design, from visualization and presentation of ideas to interactive design and brainstorming, and from concept design to final product specification. There are several good reasons for using VR in UCD and some of the most significant are discussed next.

The adoption of a UCD approach can help designers avoid the majority of usability problems (cf. Norman and Draper 1986; Norman 1999, 2002; Shneiderman and Plaisant 2009). The UCD approach is characterized by involving the users in the design process in an iterative cycle of analysis, design, and evaluation followed by redesign if necessary until the optimal solution is found. This iterative process will allow a better knowledge of user capabilities, needs, and expectations as well as their goals and the tasks required for achieving such goals. Furthermore, through this approach it is also possible to gather knowledge about the physical and social environments where the product usage will take place. The literature on user involvement in the design process is broad (cf. Kujala 2003; Hall 2001; Damodaran 1996) and it is not this chapter's purpose to present a review about this matter.

24.6.1 Virtual Prototypes, Prototyping, and Virtual Reality

When designing products, designers do not go from the concept to the fabrication stage in one step. Thus, prototypes are essential in the design process. A prototype or mock-up involves a scale model, often full size, of a product. It is used for studying, training, testing, and manufacturability analysis. In a consumer product design process, prototypes can be used, in general, to prove design concepts, evaluate alternative solutions, test product manufacturability, or just to present a product to potential users or consumers. Additionally, prototypes are needed for the iterations required by the UCD approach (e.g., Kim et al. 2004; Nevala and Tamminen-Peter 2004; Olsson and Jansson 2005; Sharma et al. 2008) since they are especially useful for collecting user feedback and permit a clearer understanding not only of the product but also of its use.

Prototyping, which is the process of developing and using prototypes for designing and evaluating candidate designs, can occur at any stage of the design process. In the early stages of the process, as in the conceptualization phase, prototypes may be primarily based on the information about the context of use via, for example, usage scenarios. In a later stage of the process, pre-production prototypes, which are already completed in every detail, can be used for testing ergonomic aspects. However, physical prototypes can be costly, and if they are of the high-fidelity type, are available only in the later stages of the design process, which will cause a delay in detecting eventual problems or mismatches in the solution under development.

Computers offer the opportunity to replace physical prototypes by digital prototypes or VPs. In the literature, the term virtual prototype has been defined in distinct ways and used for diverse purposes, which may cause confusion. Independently of the adopted definition, a VP is a computer-based simulation of a physical prototype, which must serve the same purposes and have a comparable degree of functional realism as a physical prototype with the potential to add some extra functionality. For the purposes of this chapter, we adopt the VP definition proposed by Wang (2002, 233): “Virtual prototype, or digital mock-up, is a computer simulation of a physical product that can be presented, analyzed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model. The construction and testing of a virtual prototype is called virtual prototyping.”

Using prototypes at the earliest stages of the design process will guarantee better and more profitable end-user participation (Di Gironimo, Lanzotti, and Vanacore 2006). For example, one of the first steps, which is also a critical task in the design process, involves the definition of the product concept. Having the optimal concept successfully identified at the beginning of the process will certainly increase the chances of satisfying the users. However, this task requires the comparison of many alternative solutions that, due to the difficulties involving physical prototypes, are usually made based on pictures and, as a result, rely mostly on the first visual impact of the product instead of relying on the interaction with the product. This fact can restrict the initial evaluations to mere aesthetical evaluations. By using VP, the diverse design alternatives can be immediately visualized at a relatively low cost, allowing users to give feedback about the design alternatives and their use. Furthermore, changes to the solutions can be made interactively and more easily than with a physical prototype, which means that more prototypes can be tested than financially possible otherwise. Also, VPs can either be replicas of the real products, with the same attributes (e.g., form, color, material, movement, weight, and sound), or be “super-real” products with extra attributes (e.g., textual annotations, manufacturing instructions, multiplicity of alternative designs, history, anti-gravity). By using VP, designers can turn “unreal” products into a replica of the concrete. Such products can be futuristic solutions that might be impossible to produce or whose production would be extremely expensive, such as concepts or objects of art. In such cases, all connections to reality can be completely cut off, allowing designs to break the laws of physics and achieve a greater freedom of expression.

VPs do not have to use VR, but the use of VR can contribute to taking full advantage of VPs. One of the major purposes of testing the designs is to look for product optimization. In order to test the design optimization of a VP product in the same way as the physical mock-up, a human–product interaction model is required. Ideally, the VP should be viewed, listened, and touched (eventually also smelled and tasted) by all the actors involved in its design, including the potential users, as if it was a real physical product. This is where VR can play a significant role since it can allow different alternative solutions to be evaluated and compared in quite a realistic and dynamic way, not only visually but also considering other interaction aspects such as sound and forces. The dynamics of the VR simulation, the possibility of having stereoscopic visualization and, if necessary, haptic feedback, provides an incomparable and more realistic interaction with the prototypes than possible with CAD prototypes (e.g., Dani and Gadh 1997; Weidlich et al. 2007; Whyte et al. 2000; Miedema, van der Voort, and van Houten 2009). Moreover, VR can facilitate the use and understanding of a solution in its digital form with users immersed in a VE containing both contexts of use and usage scenarios, which are discussed further in the next topic. Naturally, VR systems can offer diverse degrees of immersion, which can be chosen considering the trade-offs between the requirements of the project and the demands of the system. Associated with this aspect are the interactivity level, realism degree, and system control offered by the VR system, as discussed earlier in this chapter.

By incorporating the user, the context of use, and the VP in the product testing or evaluation, VR has the potential to allow not only aesthetic but also ergonomic features to be evaluated and optimized. Nonetheless, since the application of ergonomics in the products’ design involves an analysis of individual test subjects, in order to investigate the individual response to a product in everyday use, the availability of a VP instead of a physical prototype creates a problem for ergonomic analysis, which is how to test the use of something that does not really exists. There are several approaches to solve this issue. The first involves having a human operator interacting with the VE through haptic and/or tactile interfaces and the second is based on human virtual models, or manikins that can be either agents or avatars that will interact with the VP, in a pure simulation technique. An agent is a virtual human created and controlled by the computer, while an avatar is controlled by a real human. Another hypothesis is to integrate simulators with VR. Such a solution involves having a physical prototype that will be used by participants immersed in a simulation; e.g., flight or car driving simulators. Some examples of such an approach are: research from Caputo et al. (2001) that presents a VE that allows designers and engineers to evaluate different solutions of car interiors, starting from the early stages of the project; Deisinger, Breining, and Rößler (2000), who presented a digital platform that can combine virtual and real data in a mixed mock-up for ergonomic analysis; and Colombo and Cugini (2005), who presented an approach to evaluate product ergonomics and safety based on the use of a virtual human and simulations where the human model interacts with the virtual prototype.

Furthermore, VR can contribute to the optimization of assembly, manufacturing, and maintainability tasks (Mujber, Szecsi, and Hashmi 2004; Duffy and Salvendy 2000). Real operators can be immersed in VEs with the purpose of fulfilling an assembly, manufacturing, or maintenance task. Alternatively, digital manikins, or computer models, can be used to make those same evaluations, which is called virtual manufacturing (VM). Oudenhuijzen, Essens, and Malone (2008) give a successful example of VR for ship design, through which adoption was possible to reduce both the risk and cost of the design process. Choi and Cheung (2008) presented a versatile VP system for digital fabrication of multi-material prototypes to facilitate rapid product development.

By providing simulation techniques to analyze and improve the design of a product and its fabrication processes, the system intends to enhance collaboration and communication of the design team, considerably reduce development time and cost, and facilitate iteration with users without much anxiety about the manufacturing and material costs of the prototype. Moreover, the design can be shared via the internet with customers.

24.6.2 Product Usage Context

Every product is designed to be used in a given context that will will give rise to specific requisites for the products and demands for the users. In this way, product usability is defined as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use (ISO 1999). This means that products do not have an intrinsic usability, but instead the user, task, environment, and product features determine usability. Consequently, it is not correct to evaluate the designs without considering the usage context.

Product usage context (PUC), as defined by Green et al. (2005), refers to all factors characterizing the application and environment in which the product is used that may significantly impact customer preferences for products attributes. The PUC can include aspects such as tasks, demands, infrastructures, harshness of environment, usage duty, etc. In this sense, having a context of use is essential for a UCD approach and also to ensure the ecological validity of the evaluations made. In this respect, it should be remarked that a description of the users' relevant characteristics, tasks, and involvement, which are relevant for the product design, will result from the analysis of the context of use (for further details about context of use see Maguire [2001]). The PUC analysis requires the identification and understanding of the context of use with all its details, which is important to sustain the initial design decisions and also to become the basis for the initial evaluations of the solutions. However, the availability of a rich and realistic context of use to be adopted for systematic evaluations is not always easy. So, in most cases, the context is limited to verbal descriptions, sometimes supplemented with visual media (e.g., photographs and video). This issue encompasses one of the most relevant field vs. laboratory research trade-offs that VR can help to overcome. VR can provide an immense source of probable contexts of use, which can also include scenarios of product use—use cases. The analysis made of the usage of VP with participants immersed in a VR simulation is sometimes called simulation-based design. Such scenarios, which might be aligned with the goal of the product, can be used with the intent of presenting examples of future use, in order to help understand and clarify user requirements. The scenarios will also provide a basis for future usability tests, giving important data to establish usability goals as well as probable time to tasks completion. Furthermore, some techniques such as video recording, used to register the usage and to store information regarding user needs and abilities, might be difficult to implement in real settings since there may be constraints regarding space, security, or privacy with camera positioning as well as ethical issues with research procedures. Also, other evaluation techniques, which register various human reactions (e.g., muscle activity, galvanic skin response, heart rate, pupil diameter variation) that can be used to evaluate user experience with a given product under a context (Picard 2000), are better implemented in laboratory settings rather than in the field.

Despite all its advantages, the UCD approach, in the function of its participatory nature, may be limited by some ethical and safety constraints associated with having end users testing products. For example, the evaluation of products involving some kind of hazard for users or whose context of use can put users at risk can be an obstacle to the UCD approach. Furthermore, some products are intended for intimate use in private homes, which means that the observation of the users using the product is very restricted or even impossible.

24.6.3 Collaborative Design and Virtual Prototyping

Considering the current trend toward globalization and the need for geographically distributed product development and manufacturing, some projects might benefit from the possibility of having several experts and designers working on the same product and in the same environment at the same time. Often, new product concepts emerge from communications between participants in a design process. Computers could play an important role in the design process by providing support to the designers' creative thinking, facilitating communication and the negotiation process to achieve a compromise between different design perspectives (Tuikka and Kuutti 2000).

If prototypes and contexts of use are digital, they can be used in VEs connected by a network, allowing designers at distant locations to collaborate in the same VE. This new technological solution, known as Internet VR, can support the simultaneity of a participatory and collaborative design process (e.g., Duffy and Salvendy 2000; Huang, Lee, and Mak 2001; Shyamsundar and Gadh 2002). (For a state-of-the-art review about collaborative conceptual design see Wang et al. [2002].) With Internet VR, the resolution of design conflicts can happen early in the design process, reducing product development lead-time and manufacturing costs. Chan, Wong, and Ng (1999) proposed a collaborative solid modeling to be used through the internet, allowing multiple users to edit, synchronously, a shared solid object. The association of internet and local ethernet systems with the use of VP techniques will facilitate a mutual understanding with benefits for collaborative design and group decision making (Kan, Duffy, and Su 2001). Besides that, these internet-based solutions can also facilitate the designer–user communication (Tuikka and Salmela 1998), which is essential for the UCD process. This could also be an interesting option for projects involving users with mobility or autonomy deficits, such as a person with a specific handicap who cannot easily move to the location(s) where the project is taking place. For example, Wallergård, Eriksson, and Johansson (2008) presented a VR-based methodology that allows people with cognitive deficiencies to communicate their knowledge and experiences with the public transport systems.

Communication problems may occur during the design process when diverse "actors" are involved with their distinct levels of expertise and use of different "languages" (e.g., Bruseberg and McDonagh-Philp 2002; Carmel, Whitaker, and George 1993; Dinka and Lundberg 2006; Isomursu, Isomursu, and Still 2004; Luck 2007). Because of the availability of VPs together with rich, realistic, and interactive simulated contexts of use, VR can facilitate communication between team members and users, resulting in an increase in the speed of the design process and its effectiveness by facilitating the decision making. This is an important achievement because the iterative nature of the UCD approach may make the design process more time consuming than other design approaches, which could be incompatible with the actual global market demands and competition that have been pushing for a constant reduction in lead-time and production costs. However, if most of the manufacturing time can no longer be reduced, the product development time possibly can. For example, non-immersive VR systems might be used to display VPs as well as contexts of use into techniques such as focus groups to generate concepts (exploratory), to understand how participants interpret the reality (phenomenological), or to test a solution with the goal of evaluating product usability. (For further information regarding focus groups and other techniques for eliciting data from users, see Blomberg [1993], Bruseberg and McDonagh-Philp [2001, 2002], Caplan [1990], Macaulay [1996], and Templeton [1994].)

Finally, the computer can also log the most relevant aspects of the design process and transmit such information to all involved in the process, providing a full track that allows understanding of the entire design sequence. However, because of the lack of human contact involved in internet-based procedures, creativity can be diluted.

24.7 IMMERSIVE VISUAL REALITY TO EVALUATE HUMAN BEHAVIOR

A consumer electronic product should not only be attractive to the consumer, but to be effectively used it must also have a good functionality, be understandable, and be able to avoid or reduce accidents and human errors. In this case, the objective is not to study user motivations when acquiring a technological consumer product, but to access the knowledge about their main interaction difficulties as well as the safety and health issues related to its use. Today, when users feel they need a technological consumer product, they explore the web for the product's features, other user opinions, and look for product comparative studies before purchasing. These information sources give users a broad perspective of the product, particularly related to its usability features. Additionally, the ergonomic properties of the technological consumer product are frequently used as an argument to advertise the product or be mentioned by the salesperson in order to positively influence the purchase decision of the customer. These arguments prove that the ergonomic aspects related to usability and the safety and health of the user are a good investment for the companies.

The question now is how to guarantee that these features can be fully integrated in a technological consumer product. In interface software design this objective can be easily optimized using traditional usability tests. But, regarding consumer electronic products, this might not be easy because of the need to have a physical, fully functional prototype, which could be impossible to produce in the earlier phases of product development.

Therefore, VR with adequate methodologies could be an answer to this problem. For example, a geometrical 3D virtual prototype, with virtual buttons and displays, which incorporates a metaphor related to a conventional kitchen organization, can be developed and used as an interface metaphor for the development of a innovative kitchen concept. So, the potential users can interact with these virtual commands using a glove with tactile feedback to give sensations, such as pulses when the fingers interact with the buttons. The user strategies, performance, and errors throughout the tasks can be measured during the user interaction.

Another important aspect that becomes possible with the use of VR, is the simulation of a situation that exhibits an incorrect user behavior that could result in an accident. For example, being able to simulate the process of a user opening the stove while cooking. This behavior could cause burns to the user. With the analysis it is possible to identify equipment failure and problems in the task of cooking food and give important information to the design team for equipment modifications. The interactive process cycle combining the user evaluation results with the product changes leads to an improvement of the user interface concept to a level of acceptable quality. By using VR, this process will be easy to accomplish due to the possibility of changing the technological consumer product interface characteristics and also measuring the necessary conditions to promote almost like natural human behaviors during the interaction.

The same methodology can be implemented to evaluate the complexity of command types for an electronic consumer product control panel. In the near future, when the physical interface is inbuilt, the main challenge will be to make invisible user interfaces, which will be out of the user's sight and consciousness. The evaluation of these new interface concepts will present challenges to the professionals that use VR to improve the ergonomics in terms of usability, safety, and health of the user. The challenge will be to understand the user mental models when interacting with a technological consumer product.

24.8 CONCLUSIONS

This chapter provides information about the use of VR in technological consumer products design. Considering the particularities of technological consumer products, VR can be used in the first phase of product development to help the design team to elaborate the product design concept or later during the optimization of the prototypes in the phase of detailed studies.

It is important to say that the use of VR, within an adequate methodology, is compatible with the traditional approaches that have been used in product development representing an improvement in the product quality in terms of ergonomics.

Generally, the use of VR in the context of electronic consumer product design can be used for the purposes of

- Understanding the mental models of the user related to the operation of a system.
- Understanding the user needs and emotional feelings related to the external product characteristics.

24.8.1 Understanding the Mental Models of the User Related to the Operation of a System

Some user interfaces of electronic consumer products are so complex that it is difficult to infer the human mental model. VR can be a good approach to a better understanding of the human interactions with an interface, providing a more broad analysis. In other words, it may be difficult to study the system by stopping it or by examining individual components alone without VR. An example of this would be to try and understand how the user will react in the event of a product process error.

During product optimization, VR could be used to measure human performance, safety, and health problems as related to the different proposals of product interface solutions. In this context, the most important potentialities of using VR for this kind of study are

- The increase of the user immersion, which will enhance the human experience when interacting with the product by focusing the user attention only on the products characteristics while avoiding external variables that might influence user decisions.
- The possibility to easily change some aspects of the product appearance, like the geometry, texture, and color, or implement new interface solutions, which will result in a significant reduction in the number of physical prototypes produced.
- The possibility to simulate hazardous situations without risking the life of users and to control the ethical aspects also.

24.8.2 Understanding User Needs and Emotional Feelings Related to the External Product Characteristics

A consumer electronic product should not only generate adequate mental models, but also needs to be attractive to the consumer. With VR technology it is possible to easily simulate different virtual model concepts of a product and to measure the preferences of potential users. The cost of modeling a virtual product to be used inside a VE can be significantly smaller in comparison to the capital investment involved in the installation of any significant experimental setting involving a physical prototype in a system context of use.

In this chapter, only the potentialities of the VR for technological consumer product design were discussed. Nevertheless, several studies have confirmed that VR has considerable potential for applications in the area of workplace design (Ehn et al. 1996; Wilson 1999; Davies 2004) and the interactive design of manufacturing processes (Fisher and Coutellier 2007).

In the near future, technological development will allow a better immersion of the user through the use of other means of visualization with a larger FOV and more comfort when in use. Additionally, new developments in sensor technology will allow a more natural and comfortable use of equipment in the capture of human movement to permit an easy navigation inside the VE.

REFERENCES

Airey, J.M., Rohlf, J.H., and Brooks Jr., F.P.B. 1990. Towards image realism with interactive update rates in computer graphics. *Computer Graphics* 24 (2): 41–50.

Albright, M.J., and Graf, D.L. 1992. *Teaching in the Information Age*. San Francisco: Jossey-Bass.

Arthur, C. 1992. Did reality move for you? *New Scientist* 134 (1822): 23–27.

Auld, L., and Pantelidis, V. 1994. Exploring virtual reality for classroom use. *TechTrends* 39 (1): 29–31.

Bailey, W.A., Knox, S.T., and Lynch, E.F. 1988. Effects of interface design upon user productivity. *Proceedings of ACM CHI'88* (Washington, DC, 15–19 May), ed. J. J. O'Hare, 207–12. New York: ACM.

Bayarri, S., Fernandez, M., and Perez, M. 1996. Virtual reality for driving simulation. *Communications of the ACM* 39 (5): 72–76.

Biocca, F. 1992. Virtual reality technology: A tutorial. *Journal of Communication* 4 (24): 23–72.

Biocca, F., and Delaney, B. 1995. Immersive virtual reality technology. In *Communication in the Age of Virtual Reality,* eds. F. Biocca and M.R. Levy, 57–124. Mahwah, NJ: Lawrence Erlbaum.

Blomberg, J. 1993. Ethnographic field methods and their relation to design. In *Participatory Design,* eds. D. Schuler and A. Namioka, 123–56. Hillsdale, New Jersey: Lawerence Erlbaum Associates, Inc.

Bochenek, G.M., and Ragusa, J.M. 1998. Study results: The use of virtual environments for product design. In *Proceedings of IEEE International Conference on Systems, Man, and Cybernetics,* Hyatt Regency La Jolla, San Diego, CA, 11–14 October, Vol. 2, 1250–53. New Jersey: IEEE.

Bolas, M.T. 1994. Human factors in the design of an immersive system. *IEEE Computer Graphics and Applications* 14:55–59.

Brooks, F.P.J. 1986. Walkthrough – A dynamic graphics system for simulating virtual buildings. In *Proceedings of 1986 Workshop on Interactive 3D Graphics,* eds. F. Crow and S.M. Pizer, 9–21. New York: ACM

Bruseberg, A., and McDonagh-Philp, D. 2001. New product development by eliciting user experience and aspirations. *International Journal of Human Computer Studies* 55 (4): 435–52.

———. 2002. Focus groups to support the industrial/product designer: A review based on current literature and designers' feedback. *Applied Ergonomics* 33 (1): 27–38.

Burdea, G., and Coiffet, P. 2003. *Virtual Reality Technology.* 2nd ed. New Brunswick, NJ: Wiley-IEEE Press.

Caplan, S. 1990. Using focus group methodology for ergonomic design. *Ergonomics* 33 (5): 527–33.

Caputo, F., Di Gironimo, G., Monacelli, G., and Sessa, F. 2001. The design of a virtual environment for ergonomic studies. *Proceeding of the XII ADM International Conference* E42–E54. September 5–7, 2001. Rimini, Italy.

Carmel, E., Whitaker, R.D., and George, J.F. 1993. PD and joint application design: A transatlantic comparison. *Communications of the ACM* (Special issue on graphical user interfaces: The next generation) 36 (6): 40–48.

Caudell, T.P., and Mizell, D.W. 1992. Augmented reality: An application of heads-up display technology to manual manufacturing processes. *Proceedings of the Twenty-Fifth Hawaii International Conference on System Sciences*, Vol. II, 659–69. New Jersey: IEEE.

Chance, S.S., Gaunet, F., Beall, A.C., and Loomis, J.M. 1998. Locomotion mode affects the updating of objects encountered during travel: The contribution of vestibular and proprioceptive inputs to path integration. *Presence: Teleoperators & Virtual Environments* 7 (2): 168–78.

Chan, S., Wong, M., and Ng, V. 1999. Collaborative solid modeling on the WWW. In *Proceedings of the 1999 ACM symposium on Applied computing*, 598–602. SAC '99. New York, NY: ACM. doi:10.1145/298151.298487.

Chi, D.M., Kokkevis, E., Ogunyemi, O., Bindiganavale, R., Hollick, M.J., Clarke, J.R., Webber, B.L., et al. 1997. Simulated casualties and medics for emergency training. *Studies in Health Technology and Informatics* 39:486–94.

Cho, B.H., Jang, D.P., Lee, J.M., Kim, J.S., Kim, S.I., Ku, J.H., Kim, I.Y., and Lee. J.H. 2002. Attention enhancement system using virtual reality and EEG Biofeedback. In *Virtual Reality Conference, IEEE*, p.156. Los Alamitos, CA: IEEE Computer Society. doi:http://doi.ieeecomputersociety.org/10.1109/VR.2002.996518.

Choi, S.H., and Cheung, H.H. 2008. A versatile virtual prototyping system for rapid product development. *Computers in Industry* 59:477–88.

Chryssolouris, G., Mavrikios, D., Fragos, D., and Karabatsou, V. 2000. A virtual reality-based experimentation environment for the verification of human-related factors in assembly processes. *Robotics and Computer-Integrated Manufacturing* 16 (4): 267–76.

Coelho, C.M., Santos, J.A., Silvério, J., and Silva, C.F. 2006. Virtual reality and acrophobia: One-year follow-up and case study. *Cyberpsychology & Behavior: The Impact of the Internet, Multimedia and Virtual Reality on Behavior and Society* 9 (3): 336–41.

Coelho, C.M., Waters, A.M., Hine, T.J., and Wallis, G. 2009. The use of virtual reality in acrophobia research and treatment. *Journal of Anxiety Disorders* 23 (5): 563–74.

Colombo, G., and Cugini, U. 2005. Virtual humans and prototypes to evaluate ergonomics and safety. *Journal of Engineering Design* 16 (2): 195–207.

Crosier, J.K., Cobb, S.V.G., and Wilson, J.R. 2000. Experimental comparison of virtual reality with traditional teaching methods for teaching radioactivity. *Education and Information Technologies* 5 (4): 329–43.

Damodaran, L. 1996. User involvement in the systems design process – a practical guide for users. *Behaviour & Information Technology* 15 (6): 363–77.

Dani, T.H., and Gadh, R. 1997. Creation of concept shape designs via a virtual reality interface. *Computer-Aided Design* 29 (8): 555–63.

Darken, R.P., and W.P. Banker. 1998. Navigating in natural environments: A virtual environment training transfer study. In *Proceedings of IEEE 1998 Virtual Reality Annual International Symposium*, 12–19. Los Alamitos, CA: IEEE Computer Society. doi:10.1109/VRAIS.1998.658417.

Davies, R.C. 2004. Adapting virtual reality for the participatory design of work environments. *Computer Supported Cooperative Work* (CSCW) 13 (1): 1–33.

Deisinger, J., Breining, R., and Rößler A. 2000. ERGONAUT: A tool for ergonomic analyses in virtual environments. In *Proceedings of the 6th Eurographics Workshop on Virtual Environments*, eds. J. D. Mulder and R. van Liere. June 1–2. Amesterdam: Eurographics Association

Di Gironimo, G., Lanzotti, A., and Vanacore, A., 2006. Concept design for quality in virtual environment. *Computers & Graphics* 30:1011–19.

Dillon, A. 1988. The role of usability labs in systems design. In *Contemporary Ergonomics 88,* ed. E. Megaw, 69–73. London: Taylor & Francis.

Dinka, D., and Lundberg, J. 2006. Identity and role – A qualitative case study of cooperative scenario building. *International Journal of Human-Computer Studies* 64 (10): 1049–60.

Downes, M., Cavusoglu, M.C., Gantert, W., Way, L.W., and Tendick, F. 1998. Virtual environments for training critical skills in laparoscopic surgery. *Studies in Health Technology and Informatics* 50:316–22.

Duffy, V.G., and Salvendy, G. 2000. Concurrent engineering and virtual reality for human resource planning. *Computers in Industry* 42:109–25.

Ehn, P., Brattgård, B., Dalholm, E., Davies, R.C., Hägerfors, A., Mitchell, B., and Nilsson, J. 1996. The Envisionment Workshop— from visions to practice, In *Proceedings of Participatory Design Conference*, eds. J. Blomberg, F. Kensing, and E. A. Dykstra-Erickson, 141–152. Cambridge, MA: CPSR.

Emerson, T.C., and Revere, D. 1999. Virtual reality in training and education: Resource guide to citations and online information, http://www.hitl.washington.edu/kb/edvr/ (accessed July 2010).

Feiner, S., Macintyre, B., and Seligmann, D. 1993. Knowledge-based augmented reality. *Communications of the ACM* 36 (7): 53–62.

Fisher, X., and Coutellier, D. 2007. Editorial. *International Journal on Interactive Design and Manufacturing* 1 (1): 1–4.

Gamberini, L., and Spagnolli, A. 2003. On the relationship between presence and usability: A situated, action-based approach to virtual environments. In *Being There: Concepts, Effects and Measurements of User Presence in Synthetic Environments,* eds. G. Riva, F. Davide and W.A. Ijsselsteign, 97–108. Amsterdam: IOS Press.

Glantz, K., Rizzo, A.A., and Graap, K. 2003. Virtual reality for psychotherapy: Current reality and future possibilities. *Psychotherapy: Theory, Research, Practice, Training* 40 (1): 2–2.

Grave, L., Escaleira, C., Silva, A.F., and Marcos, A. 2001. A Realidade Virtual como Ferramenta de Treino para Montagem de Cablagens Eléctricas. In *Proceddings of 10° Encontro Português de Computação Grafica* 2001, ed. J. A. Jorge, 147–63. Lisboa: INESC. http://virtual.inesc.pt/virtual/10epcg/actas/pdfs/grave.pdf

Green, M.G., Tan, J.J., Linsey, J.S., Seepersad, C.C., and Wood, K.L. 2005. Effects of product usage context on consumer product preferences. In *Proceedings of International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. Volume 5a, 171–85. Long Beach, CA: ASME

Gutiérrez, M.A., Vexo, F., and Thalmann, D. 2008. *Stepping Into Virtual Reality*. Lausanne: Springer.

Hall, R.R. 2001. Prototyping for usability of new technology. *International Journal of Human-Computer Studies* 55:485–501.

Heldal, I. 2007. Supporting participation in planning new road by using virtual reality systems. *Virtual Reality* 11 (2/3): 145–59.

Hirose, M. 1992. Human behavior in virtual environments. In *Proceedings of the Human Vision, Visual Processing, and Digital Display III,* ed. B.E. Rogowitz, 548–59. San Jose, CA: SPIE. doi:10.1117/12.136001.

Hoffmann, H., Stefani, O., and Patel, H. 2006. Extending the desktop workplace by a portable virtual reality system. *International Journal of Human-Computer Studies* 64 (3): 170–81.

Huang, G.Q., Lee, S.W., and Mak, K.L. 2001. Synchronised web applications for product development in the 21st century. *International Journal of Advanced Manufacturing Technology* 18:605–13.

Hüsgen, S., Lulevaa, Z., and Klingaufa, U. 2006. Human computer interaction methods for a virtual reality flight and training simulator. In *Proceedings of the IEA 2006 – 16th Triennal Congress of the International Ergonomics Association – Meeting Diversity in Ergonomics*. eds. R. Pikaar, E. Koningsveld, and P. Seteels, 6 pages. Maastricht, The Netherlands: Elsevier. ISSN: 0003-6870.

ISO. 1999. *Human-Centred Design Processes for Interactive Systems, ISO/IEC 13407: 1999*. Genève: International Organization for Standardization.

Isomursu, M., Isomursu, P., and Still, K. 2004. Capturing tacit knowledge from young girls. *Interacting with Computers* 16 (3): 431–49.

Jackson, R.L., and Fagan, E. 2000. Collaboration and learning within immersive virtual reality. In *Proceedings of the Third International Conference on Collaborative Virtual Environments,* eds. E. Churchill and M. Reddy, 83–92. San Francisco: ACM.

Johnson, W.L., and Rickel, J. 1997. Steve: An animated pedagogical agent for procedural training in virtual environments. *SIGART Bulletin* 8 (1–4): 16–21.

Kallmann, M., Lemoine, P., Thalmann, D., Cordier, F., Magnenat-Thalmann, N., Ruspa, C., and Quattrocolo, S. 2003. Immersive vehicle simulators for prototyping, training and ergonomics. *Proceedings Computer Graphics International 2003 (CGI'03)*. 90, July 9–11, Tokyo, Japan, Los Alamitos: IEEE Computer Society Press. doi: ieeecomputersociety.org/10.1109/CGI.2003.1214452.

Kan, H.Y., Duffy, V.G., and Su, C.-J. 2001. An Internet virtual reality collaborative environment for effective product design. *Computers in Industry* 45:197–213.

Kensing, F., and Blomberg, J. 1998. Participatory design: Issues and concerns. *Computer-Supported Cooperative Work* (CSCW) 7 (3/4): 167–85.

Kim, G.J., Han, S.H.S.H., Yang, H., and Cho, C. 2004. Body-based interfaces. *Applied Ergonomics* 35 (3): 263–74.

Klatzky, R.L., Loomis, J.M., Beall, A.C., Chance, S.S., and Golledge, R.G. 1998. Spatial updating of self-position and orientation during real, imagined, and virtual locomotion. *Psychological Science* 9 (4): 293–98.

Krijn, M., Emmelkamp, P.M.G., Olafsson, R.P., and Biemond, R. 2004. Virtual reality exposure therapy of anxiety disorders: A review. *Clinical Psychology Review* 24 (3): 259–81.

Kuhl, J., Evans, D., Papelis, Y., Romano, R., and Watson, G. 1995. The Iowa driving simulator: An immersive research environment. *Computer* 28 (7): 35–41.

Kujala, S. 2003. User involvement: A review of the benefits and challenges. *Behaviour & Information Technology* 22 (1): 1–16.

Lee, J.M., Ku, J.H., Jang, D.P., Kim, D.H., Choi, Y.H., Kim, I.Y., and Kim, S.I. 2002. Virtual reality system for treatment of the fear of public speaking using image-based rendering and moving pictures. *CyberPsychology & Behavior* 5 (3): 191–95.

Loftin, R.B. 1993. Virtual environment technology for aerospace training. *Virtual Reality Systems* 1 (2): 36–38.

Loomis, J.M., Blascovich, J.J., and Beall, A.C. 1999. Immersive virtual environment technology as a basic research tool in psychology. *Behavior Research Methods Instruments and Computers* 31 (4): 557–64.

Loomis, J.M., Hebert, C., and Cicinelli, J.G. 1990. Active localization of virtual sounds. *The Journal of the Acoustical Society of America* 88 (4): 1757–64.

Luck, R. 2007. Learning to talk to users in participatory design situations. *Design Studies* 28 (3): 217–42.

Macaulay, L. 1996. *Requirements Engineering*. London: Springer.

Machado, L.D.S. 2003. A Realidade Virtual no Modelamento e Simulação de Procedimentos Invasivos em Oncologia Pediátrica: Um estudo de caso no transplante de medúla óssea. (PhD thesis) Universidade de São Paulo, Brasil, Escola Politécnica, São Paulo, www.lsi.usp.br/interativos/telmed/liliane_santos_machado.pdf (accessed July 2010).

Maguire, M. 2001. Context of use within usability activities. *International Journal of Human-Computer Studies* 55 (4): 453–83.

Matern, U., Koneczny, S., Tedeus, M., Dietz, K., and Buess, G. 2005. Ergonomic testing of two different types of handles via virtual reality simulation. *Surgical Endoscopy and Other Interventional Techniques* 19 (8): 1147–50.

Meyer, K., Applewithe, H.L., and Biocca, F.A. 1992. A survey of position trackers. *Presence: Teleoperators and Virtual Environments* 1 (2): 173–200.

Miedema, J., van der Voort, M.C., and van Houten, F.J.A.M. 2009. Advantageous application of synthetic environments in product design. *CIRP Journal of Manufacturing Science and Technology* 1:159–64.

Mogensen, P., and Shapiro, D. 1998. When survival is an issue: PD in support of landscape architecture. *Computer Supported Cooperative Work* (CSCW) 7 (3/4): 187–203.

Morar, S.S., and Macredie, R.D. 2004. Usability issues of desktop virtual environment applications. *Virtual Reality* 7 (3): 175–76.

Moroney, W.F., and Moroney, B.W. 1991. Utilizing a microcomputer based flight simulation in teaching human factors in aviation. In *Proceedings of the Human Factors Society 35th Annual Meeting*, Educators' Professional: Use of Microcomputers in Teaching Human Factors in Aviation, Vol. 35, 523–527. Santa Monica, CA: HFES. doi: 0.1518/107118191786754806.

Mueller, C. 1995. *Architectures of Image Generators for Flight Simulators*. (Technical Report No. TR 95-015) Department of Computer Science, University of North Carolina.

Mujber, T.S., Szecsi, T., and Hashmi, M.S.J. 2004. Virtual reality applications in manufacturing process simulation. *Journal of Materials Processing Technology,* 155–156: 1834–38.

Neale, H.R., Brown, D.J., Cobb, S.V.G., and Wilson, J.R. 1999. Structured evaluation of virtual environments for special-needs education. *Presence: Teleoperators and Virtual Environments* 8 (3): 264–82.

Nevala, N., and Tamminen-Peter, L. 2004. Ergonomics and usability of an electrically adjustable shower trolley. *International Journal of Industrial Ergonomics* 34 (2): 131–38.

Nichols, S., and Patel, H. 2002. Health and safety implications of virtual reality: A review of empirical evidence. *Applied Ergonomics* 33 (3): 252–71.

Norman, D. 1999. *The Invisible Computer: Why Good Products can Fail, the Personal Computer is so Complex, and Information Appliances are the Solution*. Cambridge, MA: MIT Press.

———. 2002. *The Design of Everyday Things*. New York: Basic Books.

Norman, D., and Draper, S.W. (eds.) 1986. *User-Centered System Design: New Perspectives on Human-Computer Interaction*. Hillsdale NJ: Lawrence Erlbaum.

Olsson, E., and Jansson, A. 2005. Participatory design with train drivers – a process analysis. *Interacting with Computers* 17 (2): 147–66.

Oudenhuijzen, A., Essens, P., and Malone, T.B. 2008. Ergonomics, anthropometry and human engineering. In *Handbook of Human Factors Testing and Evaluation*, 2nd ed., eds. S.G. Charlton and T.G. O'Brien 457–71. New Jersey: Taylor & Francis.

Page, E.H., and Smith, R. 1998. Introduction to military training simulation: A guide for discrete event simulationists. In *Proceedings of the 30th Winter Simulation Conference,* eds. D.J. Medeiros, E.F. Watson, J.S. Carson, and M.S. Manivannan. 53–60. Washington, DC. Los Alamitos, CA: IEEE Computer Society Press.

Pertaub, D., Slater, M., and Barker, C. 2002. An experiment on public speaking anxiety in response to three different types of virtual audience. *Presence: Teleoperators and Virtual Environments* 11 (1): 68–78.

Picard, R.W. 2000. *Affective Computing*. Cambridge, MA: MIT Press.

Pimentel, K., and Teixeira, K. 1994. *Virtual Reality: Through the New Looking Glass*. New York: McGraw-Hill.

Pisanich, G.M., and Heers, S.T. 1995. A laboratory glass-cockpit flight simulator for automation and communications research. In *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting* (Vol. 2, p. 951). Santa Monica, CA: HFES.

Raubal, M. 2001. *Agent-Based Simulation of Human Wayfinding: A Perceptual Model for Unfamiliar Buildings*, Vienna University of Technology, Faculty of Science and Informatics, Wien. http://www.geog.ucsb.edu/~raubal/Publications/Theses/mr_phD.pdf

Raubal, M., and Egenhofer, M. 1998. Comparing the complexity of wayfinding tasks in built environments. *Environment & Planning B* 25 (6): 895–913.

Reich, Y., Konda, S.L., Monarch, I.A., Levy, S.N., and Subrahmanian, E. 1996. Varieties and issues of participation and design. *Design Studies* 17 (2): 165–80.
Riva, G., and Mantovani, G. 1999. The ergonomics of virtual reality: Human factors in developing clinical-oriented virtual environments. *Medicine Meets Virtual Reality* 62:278–84.
Riva, G., Wiederhold, B.K., and Molinari, E. 1998. *Virtual Environments in Clinical Psychology and Neuroscience: Methods and Techniques in Advanced Patient-Therapist Interaction*. Amsterdam: IOS Press.
Rizzo, A., Schultheis, M., Kerns, K., and Mateer, C. 2004. Analysis of assets for virtual reality applications in neuropsychology. *Neuropsychology Rehabilitation* 14 (1/2): 207–39.
Rizzo, A.A., Buckwalter, J.G., Humphrey, L., van der Zaag, C., Bowerly, T., Chua, C., Neumann, U., Kyriakakis, C., van Rooyen, A., and Sisemore, D. 2000. The virtual classroom: A virtual reality environment for the assessment and rehabilitation of attention deficits. *CyberPsychology & Behavior* 3 (3): 483–99.
Rizzo, A.A., Wiederhold, M., and Buckwalter, J.G. 1998. Basic issues in the use of virtual environments for mental health applications. In *Virtual Environments in Clinical Psychology and Neuroscience,* eds. G. Riva, B.K. Wiederhold, and E. Molinari, 1–23. Amsterdam: IOS Press.
Rothbaum, B.O., Hodges, L.F., Kooper, R., Opdyke, D., Williford, J.S., and North, M. 1995. Virtual reality graded exposure in the treatment of acrophobia: A case report. *Behavior Therapy* 26 (3): 547–54.
Rothbaum, B.O., Hodges, L., Smith, S., Lee, J.H., and Price, L. 2000. A controlled study of virtual reality exposure therapy for the fear of flying. *Journal of Consulting and Clinical Psychology* 68 (6): 1020–26.
Roussos, M., and Gillingham, M.G. 1998. Evaluation of an immersive collaborative virtual learning environment for K-12 education. Paper presented at the Roundtable at the American Educational Research Association Annual Meeting, San Diego, CA.
Roussos, M., Johnson, A., Moher, T., Leigh, J., Vasilakis, C., and Barnes, C. 1999. Learning and building together in an immersive virtual world. *Presence: Teleoperators and Virtual Environments* 8 (3): 247–63.
Sadasivan, S., Vembar, D., Stringfellow, P., and Gramopadhye, A. 2006. Comparison of Window-VR and HMD display techniques in virtual reality inspection environments. In *IEA 2006: 16th World Congress on Ergonomics*, eds. R. Pikaar, E. Koningsveld, and P. Seteels, p. 5. Maastricht, The Nederlands: Elsevier. ISSN: 0003-6870
Salzman, M.C., Dede, C., Loftin, R.B., and Chen, J. 1999. A model for understanding how virtual reality aids complex conceptual learning. *Presence: Teleoperators and Virtual Environments* 8 (3): 293–316.
Satava, R.M. 1993. Virtual reality surgical simulator. The first steps. *Surgical Endoscopy* 7 (3): 203–5.
Schuler, D., and Namioka, A. (eds.). 1993. *Participatory Design: Principles and Practices*. Hillsdale, NJ: Lawrence Erlbaum.
Shackel, B. 1991. Usability—context, framework, definition, design and evaluation. In *Human Factors for Informatics Usability,* eds. B. Shackel and S. Richardson, 21–37. Cambridge: Cambridge University Press.
Sharma, V., Simpson, R.C., LoPresti, E., Mostowy, C., Olson, J., Puhlman, J.R., Hayashi, S., Cooper, R.A., Konarsky, E., and Kerley, B. 2008. Participatory design in the development of the wheelchair convoy system. *Journal of NeuroEngineering and Rehabilitation* 5 (1): 1–10.
Shendarkar, A., Vasudevan, K., Lee, S., and Son, Y. 2006. Crowd simulation for emergency response using BDI agent based on virtual reality. In *2006 Winter Simulation Conference,* eds. L.F. Perrone, F.P. Wieland, J. Liu, B.G. Lawson, D.M. Nicol and R.M. Fujimoto, 545–53. Monterey, CA: Winter Simulation Conference.
Shneiderman, B., and Plaisant, C. 2009. *Designing the User Interface: Strategies for Effective Human-Computer Interaction*. 5th ed. Reading MA: Addison Wesley.
Shyamsundar, N., and Gadh, R. 2002. Collaborative virtual prototyping of product assemblies over the Internet. *Computer-Aided Design* 34: 755–68.
Stansfield, S., Shawver, D., and Sobel, A. 1998. MediSim: A prototype VR system for training medical first responders. In *IEEE 1998 Virtual Reality Annual International Symposium,* 198–205. Atlanta, GA: IEEE Computer Society.
Steuer, J. 1992. Defining virtual reality: Dimensions determining telepresence. *Journal of Communication* 42 (2): 73–93.
Sutherland, I.E. 1965. The ultimate display. In *Proceedings of the Third IFIP Congress,* Vol. 2, 506–8. New York, May 1965.
Székely, G., Brechbühler, C., Dual, J., Enzler, R., Hug, J., Hutter, R., Ironmonger, N., et al. 2000. Virtual reality-based simulation of endoscopic surgery. *Presence: Teleoperators and Virtual Environments* 9 (3): 310–33.
Takala, T., and Hahn, J. 1992. Sound rendering. *Computer Graphics* 26 (2): 211–20.

Templeton, J.F. 1994. *The Focus Group*. New York: McGraw-Hill.
Tendick, F., Downes, M., Goktekin, T., Cavusoglu, M.C., Feygin, D., Wu, X., Eyal, R., et al. 2000. A virtual environment testbed for training laparoscopic surgical skills. *Presence: Teleoperators and Virtual Environments* 9 (3): 236–55.
Tuikka, T., and Kuutti, K. 2000. Making new design ideas more concrete. *Knowledge-Based Systems* 13:395–402.
Tuikka, T., and Salmela, M. 1998. Facilitating designer-customer communication in the World Wide Web. *Internet Research* 8 (5): 442–51.
Vincelli, F. 1999. From imagination to virtual reality: The future of clinical psychology. *CyberPsychology & Behavior* 2 (3): 241–48.
Virtual Reality. 2010. Virtual reality. In *Encyclopædia Britannica*. Encyclopædia Britannica Online: http://www.britannica.com/EBchecked/topic/630181/virtual-reality (accessed April 15, 2010).
Wallergård, M., Eriksson, O., and Johansson, G. 2008. A suggested virtual reality methodology allowing people with cognitive disabilities to communicate their knowledge and experiences of public transport systems. *Technology and Disability* 20 (1): 9–24.
Wang, G.G. 2002. Definition and review of virtual prototying. *Journal of Computing and Information Science in Engineering* 2 (3): 232–41.
Wang, L., Shen, W., Xie, H., Neelamkavil, J., and Pardasani, A. 2002. Collaborative conceptual design – state of the art and future trends. *Computer-Aided Design* 34:981–96.
Wang, Q.H., and Li, J.R. 2004. A desktop VR prototype for industrial training applications. *Virtual Reality* 7 (3): 187–97.
Warfield, S.K., Ferrant, M., Gallez, X., Nabavi, A., and Jolesz, F.A. 2000. Real-time biomechanical simulation of volumetric brain deformation for image guided neurosurgery. In *Proceedings of the 2000 ACM/IEEE Conference on Supercomputing (CDROM),* ed. J. Donnelley, 23–23. Dallas, TX: IEEE Computer Society.
Weidlich, D., Cser, L., Polzin, T., Cristiano, D., and Zickner, H. 2007. Virtual reality approaches for immersive design. *Annals of the CIRP* 56 (1): 139–42.
Wenzel, E.M. 1992. Localization in virtual acoustic displays. *Presence: Teleoperators and Virtual Environments* 1 (1): 80–107.
Whitman, L.E., Jorgensen, M., Hathiyari, K., and Malzahn, D. 2004. Virtual reality: Its usefulness for ergonomic analysis. In *2004 Winter Simulation Conference,* eds. R. Ingalls, M.D. Rossetti, J.S. Smith and B.A. Peters, 1740–45. Washington: Winter Simulation Conference.
Whyte, J., Bouchlaghem, N., Thorpe, A., and McCaffer, R. 2000. From CAD to virtual reality: Modeling approaches, data exchange and interactive 3D building design tools. *Automation in Construction* 10:43–55.
Wilson, J.R. 1999. Virtual environments applications and applied ergonomics. *Applied Ergonomics* 30 (1): 3–9.
Wilson, P.N., Tlauka, M., and Wildbur, D. 1999. Orientation specificity occurs in both small- and large-scale imagined routes presented as verbal descriptions. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25 (3): 664–79.
Witmer, B.G., and Sadowski, W. 1998. Nonvisually guided locomotion to a previously viewed target in real and virtual environments. *Human Factors (Special Section: Virtual Environments: Models, Methodology, and Empirical Studies)* 40:478–85.
Witmer, B.G., and Singer, M.J. 1998. Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments* 7 (3): 225–40.
Zahorik, P. 1997. Scaling perceived distance of virtual sound sources. *The Journal of the Acoustical Society of America* 101 (5): 3105–6.
———. 2002. Assessing auditory distance perception using virtual acoustics. *The Journal of the Acoustical Society of America* 111 (4): 1832–46.

Section IV

User-Centered Design of Consumer Products

25 Product Design: User-Centered versus a Task-Based Approach

Martin Groen and Jan Noyes

CONTENTS

25.1 INTRODUCTION

The development of new products and services is vital for commercial enterprise in order for organizations to sustain company performance (Ernst 2002). A recent survey of the consultancy company, Booz Allen Hamilton, indicated that more than 90% of top managers at organizations* in such diverse fields as aerospace, automotive products, pharmaceuticals, and telecommunications mention new product and service development as critical to achieve the enterprise's objectives (Dehoff and Neely 2004).

Having established the importance of developing new products, their development, especially consumer products (Ernst 2002) appears to be challenging. As an example, for every 100 new product ideas that entered development, 63 were terminated before market introduction. Of the remaining 37 projects, 15 became successful and 12 became commercial failures in the marketplace (Cooper and Kleinschmidt 1987, 2007; Sharma 2006). In addition, a multi-national comparison of new product introductions by 617 organizations in the United States, the UK, and the Netherlands showed that 42% were considered a failure (Hultink et al. 2000). Page (1993) found a similar level in a survey of 189 U.S. companies. In order to remain economically competitive and healthy, it is vital for organizations to develop new products, but it is evident that a significant proportion of these fail. The question arises whether there are any identifiable aspects of new product development projects that lead to a successful outcome. This will provide the focus of the first section of the chapter.

* The report does not mention the number of organizations surveyed.

25.2 DETERMINANTS OF SUCCESSFUL NEW PRODUCT DEVELOPMENT

Over the last 30 years, there has been extensive empirical research into these aspects (Ernst 2002). Studies have identified a considerable number of factors that could, potentially, affect the new product development process. Some of these factors fall outside the direct influence sphere of organizations, e.g., the legal system or the socio-political situation of the country in which the organization resides. Other factors can be influenced directly by individuals within the organization. Ernst reported a meta-review of three decades of conceptual and empirical research into the management factors affecting new product development. A study of 310 new product development projects indicated that involving the customer in a professional way in the product development stages of "idea generation, concept development, assessment and selection of prototypes and market launch" (Ernst 2002, 11) contributes considerably to the realization of commercially successful new products (see also Stewart-Knox and Mitchell 2003). However, Ernst also reports evidence that intense concentration of new product development on a few customers ("customness") has a negative influence on success. A criticism voiced by Ernst is that in the studies reviewed, the success factors for new product design suffer from methodological shortcomings; one of them being the consideration of mainly bivariate relationships, thereby ignoring the multifaceted nature of new product development. In other words, it is necessary to consider how multiple factors together influence the outcome of the product design process. For instance, Lo, Say-Wei, and Bauly (2000) subjected a 10 factor model of product development to a multivariate regression analysis to determine the extent that each factor contributed to product success. In their regression model, the predictor "user requirements" contributed 48% to the overall model. Therefore, it appears that an adequate consideration of user requirements is an important determinant in the successful outcome of new product development.

In summary, it appears from Ernst's (2002) review that involving the intended users during the design and development of the new product is positively associated with subsequent commercial success. Additionally, the number of users who need to be involved should be large enough to attain a representative and unbiased sample of the intended user group in order to prevent "customness." Hence, organizations that want to benefit from these results are required to implement sophisticated procedures into the new product development process to ensure that the needs and requirements of a representative and unbiased sample of intended users are incorporated into the design.

But how can this be achieved, taking into account these user sample recommendations? In this chapter, it is suggested that the design practice of user-centered design (UCD) could potentially address these requirements. However, some of the current recommendations concerning the implementation of UCD increase the risk of creating designs that are too specific to the user sample studied, of customness, and of commercial failure. An alternative approach to UCD is suggested. This is based on the premise of task-based design, which it is suggested could improve on current UCD practice.

The chapter is structured as follows: first, a definition of UCD is introduced; next, a number of implementation recommendations of UCD are reviewed, and some issues are highlighted. These issues are addressed in an alternative task-based approach to UCD. This proposed alternative creates an opportunity to address another long-standing design problem, namely, the issue of poor design as posited by Norman (1988). Finally, the last two sections deal with the applicability of UCD and provide some examples of products that could have or have benefited from a task-based UCD approach.

25.3 USER-CENTERED DESIGN

Involving the user in the product development process has a long history dating back to the days of Taylorism (e.g., Taylor 1911) at the turn of the nineteenth century, when some of the first time and motion studies were carried out. Since the 1960s, in the field of product design the inclusion of users in product design has been advocated as a solution to the widely acknowledged problem of poor design (e.g., Bayazit 2004; Norman 1988; Sorrell et al. 2006; Wixon, Holtzblatt, and Knox 1990).

Note that here the commercial failure of a product seems to be solely attributed to the quality of its design: this is a simplification that is critiqued in Ernst's (2002) meta-review. However, there is some evidence (Lo, Say-Wei, and Bauly 2000) that including the user requirements, one of the core elements of a UCD approach, is an important contributor toward establishing a commercially successful product.

The International Standards Organization (ISO) has made an effort to standardize UCD practices in an attempt to help improve product design. This has led to the development of the following definition (ISO 13407: 1999) of human-centered design processes for interactive systems incorporating the main thrust of UCD: "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." Although designed for the development of interactive systems (e.g., user interfaces to large databases, word processors, or spreadsheet programs), the criteria are also applicable to the design of other consumer products. For example, the definition mentions "specified users" consumer products tend to be developed for particular user groups too, such as trailing buggies for bicycles aimed at the young family market. Additionally, the definition mentions "achieving specified goals." This reflects the functionality of the product, which is also an important characteristic of consumer products, such as using a pair of scissors to cut out an item from a newspaper. The other parts of the definition, "effectiveness," "efficiency," "satisfaction," and "specified context of use," are applicable to consumer products in a similar way. It could be concluded that UCD is a concept that most people would support in terms of being a sensible addition to product design. However, it is probably fair to suggest that the concept of UCD is relatively simple in theory, but quite hard to apply in practice. The next section will consider some of the implementation recommendations that have arisen.

25.4 APPLYING USER-CENTERED DESIGN

The advice concerning applying UCD (e.g., Black 2006; or similarly for contextual design, see Wixon, Holtzblatt, and Knox 1990) seems to imply that product design should be geared toward addressing individual differences. For example, Black suggested that understanding the details of individuals' experience gives greater insight in order to develop more effective artifacts. Wixon Holtzblatt, and Knox argued that products need to be co-designed with the user, that is, partnering with users in the execution of tasks while drawing up design requirements. Corry, Frick, and Hansen (1997) asserted that the user must be the focus throughout the design process. The definition of Katz-Haas (1998) probably best describes where the focus on individual differences might lead. In her definition, UCD "is a process that focuses on cognitive factors (such as perception, memory, learning, problem-solving, etc.) as they come into play during peoples' interactions with things" (Katz-Haas 1998, 23). There are a number of issues with this approach to UCD. First, the focus on individual differences, as seems to be advocated here, leads to the risk of a fragmented design and customness (Ernst 2002). That is, revealing the individual differences requires considerable effort in time and money. Therefore, one can expect that the number of cases considered would be small. The result of this is a narrow focus on a few users, which leads to a design that is highly optimized to the needs and requirements of the users studied, but, it seems, not to those of the larger group of intended users. Additionally, Ernst (2002) found that a too narrow focus on a few customers is negatively associated with commercial success.

Another problem with the individual differences approach is that it is difficult to determine which of the cognitive factors mentioned in Katz-Haas' (1998) definition need to be considered in the design of the artifact and which can be neglected. For example, in her definition "perception, memory, learning and problem solving, etc." are mentioned. But which of these should be considered? Should only perception and memory be considered, or learning too? Moreover, if the appropriate cognitive factors *can* be selected, the next problem becomes the determination of the extent of sufficient consideration of the chosen higher order factors in order to inform the design of the artifact adequately. So, if it has been decided by the product design team that "learning" and "problem solving" should be studied in order to include the results of this study in the design of the new product, how are they going to decide when they have collected enough data, or that they need some more information. These are just two examples of many criteria that will need to be used to make this type of design decision.

There are a number of practical issues associated with the aforementioned recommendations concerning the implementation of UCD. They seem to lead to a product design approach that is resource hungry and might lead to an overly narrow focus on individual differences relating to the needs and requirements of a small sample of potential users. This could lead to a fragmented design or customness and a higher risk of producing a commercial failure. It would seem that a different approach is needed that addresses the shortcomings present in the UCD recommendations. In the next section, task-based design is suggested as an alternative.

25.5 TASK-BASED DESIGN

As implicated in the ISO definition, products are usually needed to establish some goal. Someone reaches for a pair of scissors to cut some paper, a faucet is turned to get some hot water, a television is switched on to watch the news, an MP3 player is switched on to listen to some music, etc. All these are examples of consumer products that users utilize to realize their goals. It is hard to imagine products where this is not the case. So, the functional aspect of products is an important component. This functionality characteristic of consumer products is accompanied by a specific context. That is, the establishment of some task is usually relevant in a particular context. Cutting paper is not relevant when swimming, but is relevant when creating a collage. Typing a letter is relevant at work, but not when talking to a young child.

So, approaching consumer product design from a task-based perspective allows the design team to limit the study of user interaction with the product to only those actions that are aimed at establishing the task goals. Thus, there is a natural limitation on the extent to which different psychological phenomena need to be considered in each case, that is, provided by the task and its context. The UCD question then becomes: which of the observed task-based behaviors are necessary to include in the design of the artifact?

Starting the design of a consumer product from this perspective addresses two issues. First, it addresses the issue of fragmented design and customness. That is, the product is not adapted to the individual differences of the user, but is directed at supporting the user to realize his or her goals. Since the research goals are clearer when starting from this perspective, it is more straightforward to conduct a study of a sizable number of potential users executing the task. Thus, this approach leads to a more coherent product and could prevent customness, if scientific sampling conventions are adhered to. Additionally, since the focus is on establishing task objectives, by implication the requirements of larger user groups are addressed. As an example, the required steps to make a fruit juice with a custom-made blender are usually applicable to large groups of users.

Second, it alleviates the burden on the user to find out all the intended functionality that is incorporated into the design. It is suggested that this is one of the underlying problems in poor design. This issue is the topic of the next section.

25.6 ACHIEVING GOALS WITH PRODUCTS

The use of a consumer product in order to assist a user to realize his or her goals, often requires the user to *accommodate* his or her behavior to the product in order to benefit effectively from its functionality. Another approach is the situation where the design of the product explicitly *assimilates* the task behavior of the user. In the latter case, none or limited adaptation of behavior on the part of the user is required, and it is suggested that in terms of the facilitation of good design, this would be preferable. These two approaches are discussed, respectively, in the following two subsections.

25.6.1 Product Design Requiring User Behavior Accommodation

Not taking the task-based design requirements and needs of intended end users into account could lead to artifacts that place the onus of inferring prescribed task behavior on the user. That is, if the "to be performed" task is not taken as the starting point for the design, it is up to the user of the product to discover in what way the product could be helpful to realize one or more task objectives. In other words, the user needs to *accommodate* his or her behavior to the perceived functionality of the product in order to realize task objectives. As can be seen in many examples in day-to-day practice (Gagg 2005; Norman 1988), this often fails, leading to what is then called failed designs or low acceptance of new or adapted products and services, and human error.

Human error could, we suggest, be ascribed to the aforementioned inability to infer a sufficient amount of the intended uses of a product. Perspectives on the concept of human error have varied considerably, from accounts that human error does not exist (see Senders and Moray 1991) to human error as an inevitable aspect of human behavior (Reason 2000). Attempts to control the occurrence of error has led to classification techniques (e.g., Baber and Stanton 2002; Hollnagel, Kaarstad, and Lee 1999; Rasmussen 1982; Shorrock and Kirwan 2002; Stanton and Baber 2005) that can be used to predict the occurrence of error, which should be helpful in preventing their occurrence (Stanton and Baber 2005). Reason (2000) argued that human error could be viewed from two perspectives, the *person* approach and the *system* approach.

The person approach focuses on unwelcome actions of users with artifacts, such as mistakes and violations against the prescribed behavior in dealing with the product. Actions to redress error in this approach are aimed at reducing the influence of these unwanted actions. Some examples are warning signs, adapted procedures, decisions made during recruitment, and training (e.g., Latorella and Prabhu 2000; Naikar 2006). By contrast, the system approach starts from the assumption that human error is inevitable and part of the human condition (Reason 2000). So, errors are then not the causes of an unwanted outcome, but the effects of structural errors in product usage procedures or the organizational context in which the use of the product is embedded (e.g., Edmondson 2004; Norman 1983; Rasmussen 1990). Actions to remedy errors here are aimed at preventing the occurrence of situations in which human error could occur. For example, the confirmation request when you decide to delete a computer file or the auditory warning when you forget to switch off the car headlights after turning off the engine. The occurrence of errors when using consumer products could be reduced, if the required task steps are explicit in the design of the product. If this is the case, the successive steps are supplied to the user in an intuitive way, namely, at that point and time when the user expects and needs that particular task step during his or her effort to realize task objectives. For example, the recording of a television program on a video cassette recorder used to be a task that was difficult for most people to carry out (Mark and Greer 1995). One of the reasons for this was the perplexing number of task steps that needed to be taken in order to record a television program from beginning to end. Nowadays, with the introduction of electronic program guides on personal video recorders (digital video recorders where recordings are stored on a hard drive), the task of recording has been reduced to selecting a desired television program in the electronic program guide and pressing the record button. It is a reasonable suggestion that the latter task-based design of a personal video recorder is more intuitive than that of the former video cassette recorder.

In brief, users cannot be expected to be able to infer all the intended functionality of an artifact. The users are in a different task context, and will most likely not know as much about the artifact as the designer and will have untapped needs and requirements when using the artifact. However, comprehending all the intended functionality is often needed to be able to fully accommodate the artifact in order to ensure effective, efficient, and safe use when realizing tasks. In order to come to successful design, it is suggested that the artifact needs to assimilate the task behavior of the intended user.

25.6.2 Product Design Requiring User Behavior Assimilation

Assimilating the task behavior of the user into the design of the artifact requires a thorough understanding of the relevant task activities of the user. A representative and unbiased sample of the intended user groups needs to be observed while performing a task (i.e., to prevent customness). The specific steps that users execute could be recorded and applied to inform the design team. Each relevant task step needs to be included in the design. The design should have affordances that cue the user that the product could be of use there. Some products will encompass all steps to realize task goals, while others will partly support this. As the design of the product is based on the task steps, the usability of the product intuitively fits the task needs, requirements, and expectations of the user during his or her task activity sequence toward objective establishment. Human factors psychology is well equipped to address these challenges, due to its focus on the experimental study of human task performance.

So, it is argued that requiring the user to accommodate his or her behavior in order to benefit from the provided functionality of the product to establish task objectives, seems to invite unintended usage and a sub-optimal discovery of the intended functionality of the product. As can be seen from the many documented cases of accidents with products in and around the home and garden, e.g., 4,300 people die every year in the UK and 168,300 suffer serious injury (Gagg 2005), users often do not have the expected insight to benefit from the intended functionality incorporated in the product. Making all the functionality explicitly available, in effect assimilates the behavior of the user to realize his or her goals. Adopting a task-based approach relieves the user from this difficult task of inferring the functionality, and assigns the task of making the functionality explicit to the product design team, where it is better placed as they have a more intimate understanding of the intended functionality of the product. Therefore, the quality of the design of products could be improved by assimilating user task behavior.

25.7 APPLICABILITY OF TASK-BASED USER-CENTERED DESIGN

At first glance, task-based UCD seems most applicable to product design for complex and dynamic tasks, because the aspects of the task to be considered are less straightforward. Examples of complex, dynamic tasks might include software design for larger computer applications, control room operation, surgical operations, etc. However, even the design of products that are considered generic can sometimes be improved by considering the task and context aspects of the user.

Take, for example, the design of the bathtub faucet (Roth, Patterson, and Mumaw 2002). From the user's perspective, the main goals are to control water temperature and rate of flow. Early twentieth century designs had two faucets and two spouts, one for cold water and one for hot water. This design made it more awkward for users to establish their goals. To make the water hotter while keeping total rate of flow constant required simultaneous manipulation of both faucets. Further, with two spouts, it was difficult to determine if the correct outcome had been reached. Later designs maintained two faucets but mixed the water through a single spout, which simplified the control problem somewhat. However, there remained a link between flow rate and temperature controls. More recent "single control" faucet designs provide a direct one-to-one mapping between the user's goals of controlling temperature and rate of flow. One dimension of movement of the control, usually turning, affects temperature, and a second, orthogonal movement, usually moving up or down, affects rate of flow.

This example illustrates what could be used as a criterion when deciding whether UCD is necessary to apply. When all (legal) uses of the "to be designed" or "to be amended" artifact are foreseeable, then it is not necessary to employ UCD. When this knowledge is lacking due to the complexity or dynamic character of the task and the task context, then UCD seems most appropriate. However, identifying all possible uses of a product seems to be a gargantuan task, which could well lead to omissions.

In the next section, three examples are presented that illustrate the benefit of adopting task-based design.

25.8 TASK-BASED PRODUCT DESIGN

Some examples of consumer products are presented that illustrate the potential of including task-based UCD in the product. For understandable reasons, companies are not very forthcoming with this information, so these examples are to be taken as anecdotal illustrations.

25.8.1 Ross Rifle

The Ross rifle was a straight-pull bolt action rifle produced during the middle of World War I. Originally designed for targeting practice, it did not function well during this war in wet and muddy trenches; its components clogged up too easily and the long barrel made it awkward to handle. Because of this the rifles were withdrawn from service (FirstWorldWar.com 2002; Winter 1978). It is apparent that the designers of this product did not take into account that the weapon might be used in adverse conditions, such as in the trenches. Hence, the design of the product did not assimilate the relevant task goals of the user in this wartime context.

25.8.2 Apple Newton

The Apple Newton was one of the first lines of personal digital assistants developed and sold by Apple Computer from 1993 to 1998; however, it was never as successful in the marketplace as Apple expected. One of the main reasons for its failure to interest the market was its large dimensions (height: 202 mm, width: 106 mm, depth: 31 mm). It therefore failed the "pocket test" by not fitting into an average coat, shirt, or trouser pocket (Kounalakis and Menuez 1993). One of the goals of users that had apparently not been considered was that the user wanted to carry the Newton with her or him when on the move. So, this product design did not assimilate all relevant task-objectives of the user.

25.8.3 Office 2007

In the latest version of Office 2007, the redesign of the menu has been based on a large data set of user task behavior (1.3 billion Office 2003 sessions were collected via the Microsoft Office Customer Experience Improvement Program) to inform how it should be designed (Harris 2006). This is a major attempt to use task-based UCD in order to design the product. A large sample had been drawn from the intended user group. Although biased, this does give an insight into what is needed in order to assist the user to establish his or her goals. For example, a review of the most used commands in Word 2003 led to the following top five: paste, save, copy, undo, and bold. These five commands accounted for 32% of the total command use in Word. Based on these results the paste button earned its prominent place on the left of the first tab of the menu in Word 2007.

While anecdotal, this example illustrates what the adoption of task-based design could contribute to the design of a product. The user task behavior data was used to assimilate it into the design of the user interface. This leads to a redesigned interface that should result in supporting effective and efficient task objective realization.

25.9 CONCLUSIONS

Although vital, successfully developing new products is still problematic for organizations. Studies into the factors determining commercial success have indicated that the factor "user requirements" is a main determinant in the eventual commercial success of the new product. Additionally, these studies illustrated that a too narrow focus on only a few customers often leads to commercial failure of new products. In this chapter, a case has been made for the adoption of UCD as a way to ensure that the user requirements get the place that they deserve in the design process. However, some problems have been identified with current recommendations toward implementing UCD as they appear to lead to a focus on individual differences. Following these recommendations could lead to a fragmented design and a too narrow focus on a few customers, running the risk of ending up with a commercially unsuccessful product. An alternative approach has been suggested, task-based UCD, which addresses the observed shortcomings. Moreover, adoption of this approach, it has been argued, could provide an opportunity to assimilate the design of the product toward the task-based activities of the user. In effect, this relieves the user from the burden of having to find out an adequate amount of the intended functionality in order to use the consumer product efficiently, effectively, and safely.

Including a representative and unbiased sample of users in the design of the product is an important determinant in order to design commercially successful products. The suggested task-based approach to UCD promises to be a feasible and lucrative improvement on current implementation practices. In addition, it might even lead to product designs that are more easy to use as a result of the efforts of the design team to assimilate task behavior.

REFERENCES

Baber, C., and Stanton, N.A. 2002. Task analysis for error identification: Theory, method and validation. *Theoretical Issues in Ergonomics Science* 3 (2): 212–27.

Bayazit, N. 2004. Investigating design: A review of forty years of design research. *Design Issues* 20 (1): 16–29.

Black, A. 2006 (December 4). The basics of user-centred design, http://www.designcouncil.org.uk/en/About-Design/Design-Techniques/User-centred-design-/ (accessed February 13, 2007).

Cooper, R.G., and Kleinschmidt, E.J. 1987. New products: What separates winners from losers? *Journal of Product Innovation Management* 4 (3): 169–84.

———2007. Winning businesses in product development: The critical success factors. *Research-Technology Management* 50: 52–66.

Corry, M.D., Frick, T.W., and Hansen, L. 1997. User-centered design and usability testing of a web site: An illustrative case study. *Educational Technology Research and Development* 45 (4): 65–76.

Dehoff, K., and Neely, D. 2004. Innovation and product development. Clearing the new performance bar, http://www.boozallen.com/media/file/138077.pdf (accessed April 30, 2007).

Edmondson, A.C. 2004. Learning from mistakes is easier said than done: Group and organizational influences on the detection and correction of human error. *Journal of Applied Behavioral Science* 40 (1): 66–90.

Ernst, H. 2002. Success factors of new product development: A review of the empirical literature. *International Journal of Management Reviews* 4 (1): 1–40.

FirstWorldWar.com. 2002 (October 6). Ross Rifle, http://www.firstworldwar.com/atoz/rossrifle.htm (accessed April 15, 2007).

Gagg, C. 2005. Domestic product failures – Case studies. *Engineering Failure Analysis* 12 (5): 784–807.

Harris, J. 2006. No distaste for paste (Why the UI, Part 7), http://blogs.msdn.com/jensenh/archive/2006/04/07/570798.aspx (accessed April 15, 2007).

Hollnagel, E., Kaarstad, M., and Lee, H.-C. 1999. Error mode prediction. *Ergonomics* 42 (11): 1457–71.

Hultink, E.J., Hart, S., Robben, H.S.J., and Griffin, A. 2000. Launch decisions and new product success: An empirical comparison of consumer and industrial products. *Journal of Product Innovation Management* 17 (1): 5–23.

Katz-Haas, R. 1998. Ten guidelines for user-centered web design. *Usability Interface* 5 (1): 23–36.

Kounalakis, M., and Menuez, D. 1993. *Defying Gravity: The Making of Newton.* New York: First Glance Books.

Latorella, K.A., and Prabhu, P.V. 2000. A review of human error in aviation maintenance and inspection. *International Journal of Industrial Ergonomics* 26 (2): 133–61.

Lo, F.C.W., Say-Wei, F., and Bauly, J.A. 2000. Multiple regression models for electronic product success prediction. In *Proceedings of the 2000 IEEE International Conference on Management of Innovation and Technology, ICMIT 2000* (Vol. 1), 419–22. Singapore: IEEE.

Mark, M.A., and Greer, J.E. 1995. The VCR tutor: Effective instruction for device operation. *The Journal of the Learning Sciences* 4 (2): 209–46.
Naikar, N. 2006. Beyond interface design: Further applications of cognitive work analysis. *International Journal of Industrial Ergonomics* 36 (5): 423–38.
Norman, D.A. 1983. Design rules based on analyses of human error. *Communications of the ACM* 26 (4): 254–58.
———. 1988. *The Psychology of Everyday Things*. New York: Basic Books.
Page, A.L. 1993. Assessing new product development practices and performance: Establishing crucial norms. *Journal of Product Innovation Management* 10 (4): 273–90.
Rasmussen, J. 1982. Human errors. A taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents* 4 (2–4): 311–33.
———. 1990. The role of error in organizing behaviour. *Ergonomics* 33 (10): 1185–99.
Reason, J. 2000. Human error: Models and management. *British Medical Journal* 320 (7237): 768–70.
Roth, E.M., Patterson, E.S., and Mumaw, R.J. 2002. Cognitive engineering: Issues in user-centered system design. In *Encyclopedia of Software Engineering,* 2nd ed., ed. J. Marciniak, 163–79. New York: John Wiley.
Senders, J.W., and Moray, N.P. (eds.). 1991. *Human Error: Their Cause, Prediction and Reduction*. Hillsdale, NJ: Lawrence Erlbaum.
Sharma, B.N. 2006. Determinants of new consumer product success or failure in Nepal. *Journal of Nepalese Business Studies* 3 (1): 70–77.
Shorrock, S.T., and Kirwan, B. 2002. Development and application of a human error identification tool for air traffic control. *Applied Ergonomics* 33 (4): 319–36.
Sorrell, J., Simmons, R., Desyllas, J., and Nicholson, R. 2006. *The Cost of Bad Design*. London: CABE.
Stanton, N.A., and Baber, C. 2005. Validating task analysis for error identification: Reliability and validity of a human error prediction technique. *Ergonomics* 48 (9): 1097–113.
Stewart-Knox, B., and Mitchell, P. 2003. What separates the winners from the losers in new food product development? *Trends in Food Science & Technology* 14 (1–2): 58–64.
Taylor, F.W. 1911. *Scientific Management, Comprising Shop Management: The Principles of Scientific Management [and] Testimony before the Special House Committee*. New York: Harper.
Winter, D. 1978. *Death's Men.* London, UK: Penguin.
Wixon, D., Holtzblatt, K., and Knox, S. 1990. Contextual design: An emergent view of system design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Empowering People,* 329–36. Seattle, WA: ACM Press.

26 Needs Analysis: Or, How Do You Capture, Represent, and Validate User Requirements in a Formal Manner/Notation before Design

K. Tara Smith

CONTENTS

26.1 INTRODUCTION

User-centered design, according to Katz-Haas (1998), is about defining who the users are, defining their tasks and goals, their experience levels, what functions they want and need from a system, what information they want and need, and understanding how the users think the system should work.

This chapter is about how to write down these elements of a user-centered design process, translated into formal requirements, so that a design team can implement them into a successful and usable design. I refer to this process as "needs analysis" to distinguish it from the system engineering requirements analysis process, although I do use the term "requirement" throughout.

This needs analysis process is assumed to be in the early stages of an overall user-centered design process, so I am not discussing standard human factors techniques, such as task analysis, target audience description, etc. I am also assuming that the business case is complete: the business case will aim to give the user what they want, even if this is not always specifically articulated, as this is the basis of a successful product. It could be seen as an advantage to the human factors/usability community to ensure that the usability issues are addressed in the business case, but that is outside the scope of this chapter.

Throughout this chapter, I am using examples based on a washing machine and occasionally a DVD player to illustrate the points. For the most part, these examples are simplified and are not meant to inform the future design of these products. To try to prevent long and unwieldy sentences, I am using the term "device" to refer to the thing being designed, whether it is a product, system, tool, etc., and the term "user" to cover end users, customers, purchasers, etc. This is not meant to imply that there are not important differences between them that must be considered.

26.1.1 A Traditional Approach

- Think of what is right and true.
- Practice and cultivate the science.
- Become acquainted with the arts.
- Know the principles of the crafts.

(Musashi 1994)

These four principles (or rules) were proposed over 300 years ago, describing the nature of training for and employing martial arts. However, they are equally applicable to the practice of human factors.

Taking each one in turn, we need to translate it into something more meaningful to the needs analysis process.

Think of what is right and true—first, we need to understand what requirements are and why they are important. We need to have a framework for discussing them that fits their use.

Practice and cultivate the science—this is to do with asking the right questions and understanding the nuances of the relationships between different types of requirements and the issues that impact on the way requirements are captured and phrased.

Know the principles of the crafts—this is to do with applying the understanding of the science and having adequate tools and frameworks to ensure the overall success of the project.

Become acquainted with the arts—this is to do with the understanding of ensuring elegant design solutions are created as a result of the implementation of the requirements.

Additionally, it has always been a rule of thumb of all craftspeople to measure twice and cut once. In other words, check and validate your requirements before committing to a design solution.

26.2 FRAMEWORK—THINK OF WHAT IS RIGHT AND TRUE

This chapter is about the creation and use of requirements statements in the design process. The needs analysis process described here can be used for any product or system, but is most prevalent in complex or critical systems.

Wikipedia defines requirements as being typically placed into the following categories:

1. Functional requirements describe the functions that the system is to execute, e.g., formatting some text or modulating a signal. They are sometimes known as capabilities. Functional requirements are, by their nature, statements that represent a single independent functionality that needs to be implemented by an engineer.
2. Non-functional requirements are ones that act to constrain the solution. Non-functional requirements are sometimes known as constraints or quality requirements. They can be further classified according to whether they are performance requirements, maintainability requirements, safety requirements, reliability requirements, or one of many other types of requirements.

Unfortunately, I do not find this definition useful when considering a human factors approach as this separation of requirements into functional and non-functional does not necessarily suit the user-centered design process. The usability issues, which are often put under non-functional requirements, are also capabilities that unfortunately have no single independent design solution.

Real requirements can be complex and often have extensive ramifications. My son, in his second-year systems engineering course, asked about non-functional requirements and was told, "they are too difficult to consider and we won't be covering them in this part of the course." This lecturer is not the only person to feel this way about them as the following example illustrates, but real requirements although often complicated and difficult to handle are crucial.

> A real example: I was called in to assess a military field system and was shown an application that was basically Microsoft Office-like. When I pointed out that there was a requirement that this thing was to be used at night, in protective clothing (gloves, face mask, etc,), in the field (in a tent or the back of a vehicle), in extreme environments (jungle, desert, etc), the engineer replied that yes there was such a requirement and he believed that somebody could use it in those circumstances, but the requirement was a "non-functional" one, which was untestable. He then went on to tell me that the operational performance criteria were going to be tested in an office environment and that no test had been planned for any field use.

A requirement, no matter whether it is a functional one or something else, must have an owner and an object. The requirements for one device are likely to have both a variety of owners and a variety of objects. In this chapter, I am going to concentrate on the owners of requirements who are also potential users, as this impacts most on the tasks to be carried out with the device.

For example, the user (owner) may require to be able to select a particular washing setting (object) on a washing machine; the company making the washing machine (different owner) may require the same control unit to be used for all their nationality variations (different object). Both of these requirements are real requirements (needs) on the design team, they are both related to the business case for the reason to develop the product in the first place and they both need to be understood by the design team. Functional requirements may be derived from these, as instructions to an engineer, but the understanding of these user needs and the testing against these user needs is the key to ensuring user-centered design is taken all the way through to implementation.

This chapter will focus on understanding how to capture and use real requirements (needs) expressed from the end user's perspective.

26.2.1 Requirements are Important

Design today is about multi-disciplinary teams coming together to produce credible and saleable products. The nature of specialization in aspects of design has meant that no one individual can have a detailed and thorough control of the components of the design to the extent that ensures a successful business solution is created. Any design authority or system engineer must depend on the expertise of the members of their design team. Because of that one fact it is critical that the design team are working to a common vision of what the system is meant to achieve and that this vision is related to the business case driving the development.

A real example: I was brought in to improve the human-computer interaction (HCI) of a chemical plant control system that monitored and controlled the flow of liquids and gases throughout a production line. The engineers had concentrated on the complex functional requirements of the system and totally missed the need to provide an audit trail for quality and safety control purposes. They had focused on the difficult bit and on ensuring that their system would accommodate 100% of all possible variations, but had missed one of the fundamental reasons why the system existed in the first place, which was to support the quality and safety monitoring of the plant.

Truly understanding and implementing user-centered real requirements is often the distinguishing feature in market success. Therefore, the process of identifying and deriving these requirements is critical.

It is important to remember two distinct facts about this process:

- The entire requirements process is there to support the understanding of the end user's needs by the developer.
- The above should not be confused with the use of these requirements contractually to scope the development.

26.2.2 What are Requirements?

A distinction is often made between user requirements and system requirements, where user requirements are expressed from the point of view of a user being able to achieve something while system requirements are expressed in terms of what the proposed system is going to do to allow the user to do what they want to do.

To allow the discussion of different sorts of requirements, this chapter will separate requirements into the categories shown in Figure 26.1, where the arrows represent the process of developing the requirements. As this may be starting to get a little confusing, Table 26.1 gives an illustration of the type of requirements I am talking about, using a washing machine as an example.

As can be seen from Table 26.1, the key requirement for the design concept is the user-expressed real requirement (need) and the key requirement for implementing the design is the system-expressed functional requirement. This chapter is concerned with how and why you derive user requirements down to a useful level, prior to developing them into system requirements.

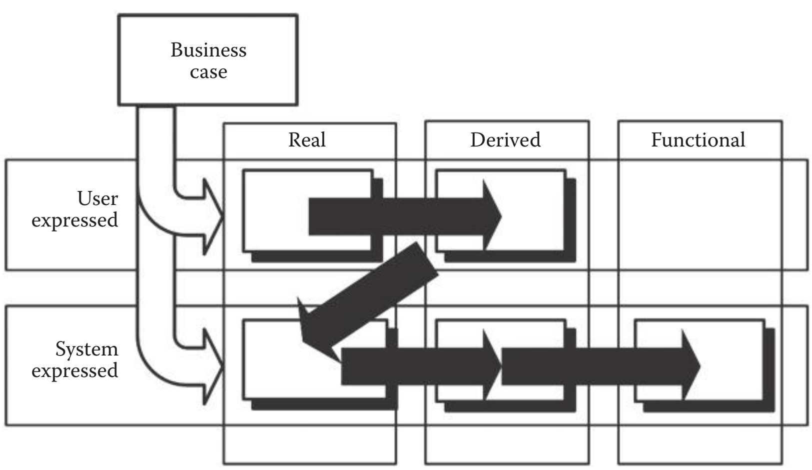


FIGURE 26.1 Requirements development process.

TABLE 26.1
Example Requirements Development

Washing Machine Requirements	Real	Derived	Functional
User expressed	The user requires their laundry to be done.	The user wishes to be able to select appropriate washing programs. The user wishes to be able to easily load and unload the washing machine.	
System expressed	The washing machine shall provide a mechanism for the user to select the appropriate washing cycle. The washing machine shall be easy to load/unload.		The washing machine shall heat water to the correct temperature. The washing machine door shall have a minimum diameter of xxx. The washing machine shall have a minimum capacity of xxx.

It is the contention of this author that, specifically related to user-expressed real requirements, not creating derived requirements before moving on to system requirements is often the cause of the system not meeting its business case. In other words: real requirements can be used to judge the likelihood of meeting the business case. Testing against functional requirements only (i.e., not considering the users' needs) may result in the design not meeting these real business case requirements.

This makes it sound very simple; unfortunately, collecting and articulating the users' needs are not always straightforward.

Steve McConnell's (2003) book, *Rapid Development*, details a number of ways that users can inhibit requirements gathering:

- Users don't understand what they want
- Users won't commit to a set of written requirements
- Users insist on new requirements after the cost and schedule have been fixed
- Communication with users is slow
- Users often do not participate in reviews or are incapable of doing so
- Users are technically unsophisticated
- Users don't understand the development process

All these are true; however, users do not need to understand any aspect of the design, development, or engineering process to use the products of these processes. It is the job of the human factors professional to help the users articulate their needs and devolve them into more detailed requirements so that these issues are avoided.

There are some issues to do with the nature of requirements that are often ignored. Most real user requirements are multiple and complex in that they are constantly cross-related, e.g., medicine containers should be "child-proof" but at the same time accessible to elderly and frail users. This means that either you can develop contradictory functional requirements or you can develop system requirements that do not cover all logical alternatives.

Requirements are not a mechanism to resolve logical domain conflicts. Requirements often conflict: the requirements development process is, in essence, the art of creating an optimum compromise between conflicting requirements.

To summarize:

- Requirements are complex and can conflict.
- Requirements build a bridge from the business case to the design.
- Requirements help to identify trade-offs that need to happen in the design process (i.e., where a design cannot resolve the requirement conflict).
- Requirements are there to unify the multi-disciplinary design team; enabling them to meet their business case through a common vision.
- Users often do not speak the same language as the development team.

26.3 ASK THE RIGHT QUESTIONS: PRACTICE AND CULTIVATE THE SCIENCE

In this section, I am not going to talk about creating a detailed business case, but it is sometimes useful to think of these questions in that context. Commonly, I ask four basic questions, though there could be more that are specific to any one design area:

- Why is there a necessity to add a human component to the requirements?
- What type of device do you envisage making?
- What types of requirements are necessary to ensure success?
- What are the integration issues to do with the relationships between the requirements?

Let us examine each of these questions in turn, as the answers to all these questions may change the flavor of the requirements.

Why is there a necessity to add a human component to the requirements? The essence of this question is again more understandable from a business case perspective. Why is it important to the business case that the human component is considered? Is it that the business case relies on the system being perceived as "better" by its current users? Or is it that it needs to be perceived as better than its competitors? Or is it related to the overall performance requirements of the system that can only be judged in the light of the human operator? Alternatively, is it because this is a one-shot development and it is critical that it is successful the first time?

What type of device do you envisage making? This question may seem obvious but, in my experience, it is all too often overlooked. Is the device that you are designing supporting an individual process or system: like a washing machine does by taking dirty clothes and converting them into clean clothes? Is it a system that enables a secondary task: like a DVD player, where the desired task is to watch a DVD not to operate the remote control? Or is it a piece of modular equipment: like a power tool that can have different fixtures and features added to it, where these fixtures and features might be developed separately from the power tool itself?

What types of requirements are necessary to ensure success? Here I believe, within the human factors area, there are five main categories of requirements:

Utility: What the device actually does and what is the relative importance to the end user of any individual feature. It is often useful to rank the relative priorities of the different utilities of the device, i.e., what are the most important functions?

Operational performance: Performance measures of the overall operation of the person with the device.

Accommodation of user population: What populations must be able to use the device, e.g., elderly, disabled, under 16s, Japanese, expert users, etc.

Adoption: The relative market position of this device in respect to its competitor devices.

Extendibility: How easy it is for the user to extend the utility of the device.

The extent to which requirements need to be placed in these different categories depends, to some degree, on what type of "device" it is. For example, if it is a tool then aspects to do with its extendibility

TABLE 26.2
Example Requirements Ranking Sheet

	Existing System	Competitor 1	Competitor 2	Competitor *N*	Target for New System
Utility					
Operational performance					
Accommodation of user population					
Adoption					
Extendibility					

may well be key; whereas a process-centered device like a washing machine might not have any extendibility and would probably concentrate on utility and accommodation of user population.

It is often a telling activity to produce a simple chart that rates these requirements against their priorities. It can be simply filled in with a 1–5 scoring system or a ranking. Additionally, each key requirement in each of these categories can also be ranked (Table 26.2).

What are the integration issues to do with the relationships between the requirements? This is commonly tackled by identifying the impactors on the user community. For example, criteria may be set for using an automated telling (bank) machine (ATM) where impactors such as time of day, weather conditions, lighting, etc., may modify the individual user-expressed requirements. This in effect means that these human-related requirements, to be truly understood, need to be multiplexed with the environmental impactors in order to generate individual derived requirements.* Likewise, some user needs and system requirements may also need to be multiplexed. It is not good enough to say that the screen text has a contrast ratio of xx and separately that it should be suitable for all weather and lighting conditions: these two requirements must be multiplexed to system requirements that represent the testable gamut of the two requirements.

To summarize:

- Formulate and ask questions to do with the business plan that provide an indication of the human aspects of the system, including the relative merit of functionality.
- Express these findings from the user's perspective.
- Cross-relate them to each other and to the impactors on the activity.

26.4 UNDERSTAND THE REQUIREMENTS: KNOW THE PRINCIPLES OF THE CRAFTS

The requirements are there for the purpose of the design team gaining understanding. This section is about actually writing the requirements down in a usable form—this is always more difficult than it sounds.

It is common practice that requirements are used to test a design or the implementation of a design to see how well it fits, so there is an awful lot written in the field of requirements engineering about the use of requirements for validation purposes after a system has been built. It is often referred to as the system engineering "V" diagram, where user requirements lead to build, which leads to system validation (Figure 26.2).

Unfortunately, this approach does not cover the validation of the requirements to ensure that they are correct and complete. Validating a design against incomplete or incorrect requirements does little to support the achievement of your business case.

Therefore, the first activity that you are going to do with the requirements should be to use them to support a requirements validation exercise. For instance, are these requirements correct? Are they complete? Do they represent a successful business case? If they don't, change them until they do.

* In this context, multiplex means "combining many requirements into a single set of requirements."

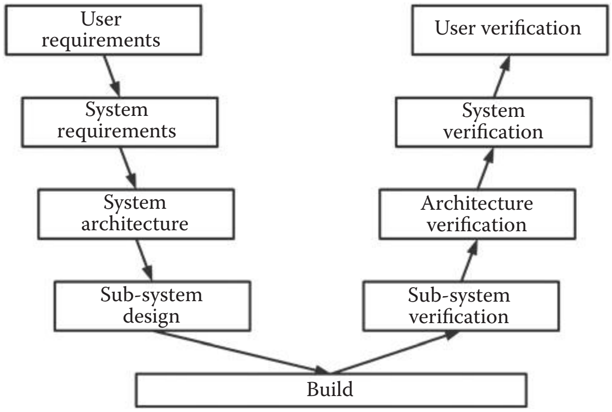


FIGURE 26.2 System engineering "V" diagram.

A real example: I was brought in to assess a multi-user software system, which needed to be rapidly deployed and configured in response to emergency situations, where the system engineer had logically broken down every aspect of every role so that in configuring user permissions, you had to go through three pages of settings for each user. Additionally, if any staff changed while the system was in operation or required additional permissions to be given, they had to log off the people who currently had those permissions (interrupting their work), re-allocate all the permissions, and then log everybody affected back on again.

This solution satisfied all the system requirements that had been generated, however this system is meant to be used in emergency response conditions. If the users' needs had been adequately captured and validated early, the system requirements would have been specified differently.

The conundrum faced here by the analyst is that requirements often cannot be validated until they have been derived and written down, which means that this process is often iterative and can lead to the late identification of additional or amended requirements. Therefore, it is critical to timetable sufficient activity to reduce the risk of incorrect, incomplete, or late requirements.

The next stage is to formulate the requirements statements. Requirements statements have to be written in a very formal manner. This may make them appear repetitive and dry to a casual reader, however their precise wording can be crucial. All too often, user requirements (needs) are transposed into system requirements and decomposed into a logical structure. These logical options may bear no resemblance to the user's model of how the system should work.

To take the example of a washing machine, one of the top level user-expressed real requirements (needs) is

- The user requires to be able to wash 95% of their clothes in the washing machine.
  Some clothes are made of wool and washing woollens requires low temperatures and slow spin speeds.

Moving directly to system-expressed derived requirements could give:

- The system will allow the user to control the wash temperature
- The system will allow the user to control the spin speed

These derived system requirements are likely to lead to a washing machine where you set the temperature separately from the spin speed separately from the duration of the wash, allowing complete customization.

However, if the top level user-expressed real requirement was decomposed to a user-expressed derived requirement, it could give:

- The user requires to be able to instruct the system to wash woollens
- The user requires to be able to instruct the system to wash synthetics

This would lead to the design providing a selection of common combinations of temperature, speed, and duration (e.g., for cotton, wool, synthetics, quick wash, etc.).

This is a bit of a simplified and artificial example, but the logic holds true: moving from top-level user requirements (needs) to system requirements too early, moves the design away from the users' mental models.

So, the important thing here is to take the real top level user-expressed requirements (needs) and decompose them to low level user-expressed requirements before deriving them into system requirements or functional requirements. The question is what is the user's detailed requirement? How does the user consider these issues?

Again in our washing machine example it may be discovered that there is more than one mental model of categories of clothes and their corresponding wash cycles. You could decide that your solution is to go with one users' mental model only and educate your users either through signage on the machine or increased signage on the clothes. This is a design trade-off that can be made once you have understood the requirements. The multiple requirements still exist, but the designer has made a decision to make this design trade-off.

This is all to do with asking questions, deciding which category of requirements you are asking about, and ensuring that the questions about each category are answered and complete. Do not start translating user-expressed requirements into system requirements until you have ensured that the user-expressed requirements represent the true picture of the user's needs and are complete and you have multiplexed them with the other external (environmental) issues.

> A real example: I was brought in to help with the design and specification of a mobile phone base station test system and it was stated in the business case that no user would be required to take this equipment up a mobile phone mast. Every interviewee confirmed that they currently and regularly took the predecessor equipment up the mobile phone mast and that they would be required to do the same with the new equipment. This single fact changed the physical criteria for the shape and weight of the system as well as adding the need for one-handed operation (from multiplexing the environmental requirements of climbing a phone mast).

Now to writing down the requirements statements.

The following formula requirements statements are intended as useful examples, not as an exhaustive list. Additionally, as English is not a logically constructed language, you can find that the sentence is not grammatically correct at the end and needs "tweaking." This formulaic approach to constructing requirements statements allows lists and categories derived from other human factors activities (such as task analyses, target audience descriptions, etc.) to be easily included in the requirements statements.

Some of these variables (shown between < and >) are the same for all types of requirement statement. They are

<**requires**> could be "does not require"—it is important to make the distinction between something being "not required" and something being "required not to." For instance, it can be a positive or negative requirement.

<**the object**> can be the device, the capability of the device, an aspect of the device (such as controls, size, color, etc.), etc.
<**perform**> what the user is to do to the object for this requirement, such as load, start, stop, operate, etc. This will be an aspect of the task analysis.
<**demographic**> a definable user group or groups.

Utility statement
The user <**requires**> <**the object**> to have <**enough**> <**ability**>
Where
<**enough**> could be a relative or specific quantity—e.g., 50%, more than competitor/previous/current, etc.
<**ability**> could be usability, supportability, functionality, etc.

Operational performance statement
The user <**requires**> <**the object**> to <**criteria**> <**perform**> such that the resultant manned system exhibits the following behaviors:
<**sub-criteria** > <**sub-perform**>
Where
<**criteria**> a performance criteria such as quickly, easily, without error, etc.
<**sub-criteria**> quantifies or otherwise specifies the performance criteria, e.g., if the criteria is "quickly" the sub-criteria could be "in less than 30 seconds."
<**sub-perform**> can be the same as <**perform**> or can be more specific: e.g., if perform is "start" the sub-perform could be "select program."

Accommodation of user population
Users belonging to <**demographic**> when using <**the object**> will <**perform**> <**criteria**>
Where
<**criteria**> is the level that the users perform at: e.g., 50% of the time, with no more than 10% errors, etc.

Adoption
<**criteria**> of the <**demographic**> will <**adopt**><**the object**>
Where
<**criteria**> could be relative or specific quantity, e.g., 8 out of 10, 50% of users of competitor systems, more than use the current system, etc.
<**adopt**> could be use, buy, early adopt, adopt, etc.

Extendibility
The user <**requires**> <**the object**> to provide the ability to be adapted by future envisaged amendments such that the resultant device provides the ability for <**future use**>
Where
<**future use**> could be the ability for <**the object**> to be adapted by future envisaged amendments, the ability for future functionality to be added and/or <**the object**> to be used in ways that it was not originally intended: e.g., attaching it to a bigger device, attaching additional devices, etc.

This formal, formula-based approach provides the analyst with a method for ensuring that all the data gathered in the task analysis, user profiles, target audience descriptions, focus groups, etc., are included in the <**variables**> of the requirements statements. It allows a simple cross-check to be carried out between the data gathered and the derived requirements statements to test for completeness: all the data should be reflected somewhere in the list of <**variables**>. This list can also prompt the consideration of new combinations for requirements: e.g., the <**criteria**> "safely" might not originally have been associated with the <**perform**> "unload."

Additionally, any of these formula statements could be amended to have a <**demographic**> instead of the user.

26.4.1 Testing Statements

As testing toward the end of the design process is a high-risk development strategy (i.e., it is late in the process for changes to be made, so re-work is likely to be expensive), I believe that you need three stages of test criteria.

The first stage is the test that you are going to apply to the requirements statements to check their validity.
The second stage is to validate that the concept of the design matches the users' mental model and that any trade-offs are going to be acceptable.
The third stage is to validate the implementation of the design.

To illustrate: we could have a criteria that all users of DVD players would like a feature that allows them to skip over the announcements/adverts/trailers at the beginning of a film (this is a utility example).

To test whether this requirement is valid: you might have identified that this is desirable from focus groups, so the first stage test would be based on the percentage of people at a subsequent focus group that would find this feature desirable. The second stage test may be based on a prototype and the number of people that actually used the feature during a user trial or mock-up. The third stage test could be asking whether the way that this feature has been implemented fits the mental model of the users.

This three-phase approach to testing the requirements drastically reduces the risk of the design not meeting the business case. You can still use the standard human factors techniques, such as surveys, focus groups, questionnaires, user trials, etc., they are just applied against requirements statements rather than against a design.

To summarize:

- Allocate sufficient time to check and validate your requirements.
- Ensure that all requirements are derived as low level user requirements before being transposed into system requirements.
- Word your requirements precisely and ensure that you cover all categories of human-related requirements.
- Create test statements to validate the requirement, the concept, and the implementation.

26.5 VALIDATE AND IMPLEMENT THE REQUIREMENTS: BECOME ACQUAINTED WITH THE ARTS

This section focuses on validating the requirements generated previously. The basic conundrum faced by the analyst is now that you have decomposed your understanding of the user's requirements to the lowest entity, you have to look at collapsing those requirements into key points that can be discussed. This can be done either by focusing on the top level user-expressed real requirements (needs), or by identifying contentious or conflicting requirements that need better understanding before being resolved, or a combination of both.

This process is obviously going to involve users or user groups and there is plenty written about the general conduct of interviews, focus groups, etc. What I am going to focus on here is the issues involved in using these types of methods to validate requirements.

At this point, we must remember, as has been previously pointed out by Steve McConnell, that there are many problems in getting users to express and articulate their tasks, goals, needs, and desires.

My favorite method for dealing with this is to use what I term a "Blue Peter"* prototype approach: either in conjunction with a focus group or with individual users. Characteristics of a Blue Peter prototype are that it is quick, cheap, and easy to make, it may represent only one aspect of the device and it is easily modifiable. The process goes:

- You introduce and initially discuss and get some feeling about the issue involved—often you can do this by talking about what the users have at the moment and what is good and bad about it.
- Bring out the prototype (here's one I made earlier) that represents some of the non-conflicting concepts captured—it could be a picture, cardboard model, PowerPoint presentation, etc.
- Now introduce variations based on the conflicting/contentious requirements.
- Gather opinions on the variations.

This process could be done in one session; it could be done as steps through an initial design; it could be spread out over several weeks or even months.

The very next thing you should do is throw all the Blue Peter prototypes away. These prototypes are there to generate discussion: they are not proposed design solutions. It is important not to get overly focused on a design solution before all the requirements are crystallized.

To go back to our washing machine example, if the feedback from these focus group-type activities was that only having pre-defined wash programs was too restricting and that the chief concern was about heat on delicate articles, this could be added as a requirement:

- The user requires the ability to reduce the wash temperature of a standard washing cycle.

The way that this requirement would be implemented could be very different from the completely customizable machine described earlier.

Focus groups are often used as a down-selection mechanism; however, what we are talking about here is using the same mechanisms to capture the nuances of the real requirements. It is by understanding those nuances during the design process that you produce an elegant design. During this requirements crystallization process, do not present the requirement to the potential users/focus groups; present what the requirement means to them.

> A real example: A project produced a 500-page requirements document, formatted as one huge table in 8 point font, gave it to their customer and said "is this what you want then?" The customer sort of read it, and assumed that it expressed their real requirements because it had been given to them by "experts" in analysis.

Unfortunately, it is the nature of people to do two things when faced with describing something they want or need:

- They express their want as a solution that is not necessarily thought all the way through to make a coherent design.
- They tend to focus on what will satisfy them, rather than the ideal: as they think that they are being helpful and saving you effort.

* A prototype made of "sticky-backed plastic and toilet rolls" as in the BBC children's program.

It is crucial to always focus on understanding why they think they need the feature they are describing or why they think they would be satisfied with what they have described. In other words, do not accept their first answer: keep on asking questions until you have a clear understanding of what their real requirements truly are.

To summarize:

- Validate your requirements with users.
- Accept that there may still be contradictory requirements.
- Understand the nuances of the requirements and ensure that these are reflected in the precise wording of the requirements.
- Keep asking your users until you have a true understanding of their requirements.
- Elegant design can only be created from that understanding of the nuances of the users' needs.

26.6 CONCLUSION: SUMMARY OF SUMMARIES

- Creating requirements statements helps the development team formulate a common picture of the users' needs.
- Deriving detailed user-expressed requirements is necessary to support the user-centered design process.
- Validating requirements with users prior to committing them to a build reduces the risk of re-work.
- All requirements are testable; however, tests may not yield conclusive results.
- Requirements can be contradictory or conflicting: design is the art of reconciling requirements into an acceptable compromise.
- Undertaking a formal process provides better visibility of the completeness of the requirements statements.

If you do not derive real user requirements and validate them in a systematic way, you will waste time and/or money.

To end where we began, Miyamoto Musashi's ninth rule is "Do not do anything useless."

REFERENCES

Katz-Haas, R. 1998. Ten guidelines for user-centred web design. *Usability Interface* 5, 1.
McConnell, S. 2003. *Rapid Development.* Redmond, WA: Microsoft Press.
Musashi, M. 1994. *The Book of Five Rings.* Boston and London: Shambhala.

27 Users' Interactions with Design Models

M. J. Rooden and H. Kanis

CONTENTS

27.1 INTRODUCTION

Observational studies such as user trials are at the core of user-involved product assessment. Potential users are observed when operating a product. Generally, their activities reveal usability problems. It is commonly accepted that the earlier in a design process that usability problems can be identified the better, as the opportunity for improvement by design is less complicated in early phases. During the early phases of a design process, prospective users may be observed operating design models, e.g., drawings, foam models, computer simulations, or prototypes (cf. Moggridge 2007). In our study, a design model represents a design at some point in its development (Figure 27.1). The assumption underlying user trialing with design models is that participants will indeed approach the model as representing a design.

Budgets (both time and money) may prevent characteristics already identified, from being accurately represented in a design model (de Bont 1992). In addition, design processes are about the identification and definition of characteristics of a new design. This means that representation of a full range of characteristics in material form is out of the question during an ongoing design process. Hence, differences between a design model and an intended design are inevitable to some extent and may introduce "artificial" ways of usage in observational studies, or may prevent usability problems from emerging in such studies.

Only a limited number of studies address the question of which characteristics of a design, represented in design models (e.g., aesthetic refinement, color, materials), do or do not reinforce user activities similar to those with the actual design (see Fay, Hurwitz, and Teare 1990; Wiklund, Thurrott, and Dumas 1992; Prümper, Heinbokel, and Kuting 1993; Virzi, Sokolov, and Karis 1996; Rooden 2001). Recommendations on the construction of design models for user trialing are scarce. On the basis of a study with an electronic dictionary and four design models, Wiklund, Thurrott, and Dumas (1992) conclude that there is no penalty for creating a prototype with limited aesthetic refinement. Another finding is that inter-individual differences in users' approaches to design models and the

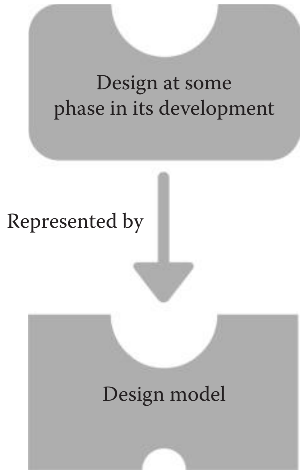


FIGURE 27.1 A design model representing a design at some phase in its development.

consequential differences in user activities may prevail over the general effects of certain model characteristics on usage (Virzi, Sokolov, and Karis 1996; Rooden, Green, and Kanis 1999).

The objective of this chapter is to gain insight into the interpretations of design models by prospective users. The link between a design model and an intended design (see Figure 27.1), as defined by the designers involved, is not available to participants in a user trial. So, with the focus on prospective users' interpretations, in this study we are not talking "designer models" (cf. Norman 1983). The question to be answered is whether potential users will indeed interpret a design model as some representation, and, if so, how they imagine a functioning product on the basis of that model, as illustrated in Figure 27.2.

27.2 METHOD

27.2.1 Design Models

A series of user trials was carried out, in which prospective users were observed operating both design models and a real product (Rooden 2001). The product chosen was a blood pressure

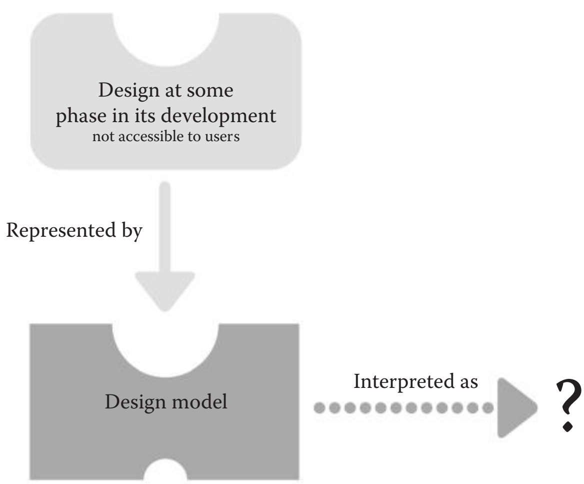


FIGURE 27.2 What does a design model represent in the viewpoint of prospective users?

FIGURE 27.3 The OMRON M1 blood pressure monitor.

monitor for home use (OMRON M1, Figure 27.3). Three design models were included: (a) a set of drawings, (b) a foam model, and (c) a final appearance model (Figure 27.4). The models were constructed by the researchers, and the choice of these models derived from the primary aim of the study: investigating the effects of differences in characteristics between design models and a functioning blood pressure monitor on (simulated) usage (i.e., use actions and usability problems; Rooden, Green, and Kanis 1999). All three models were considered recognizable as not being functioning blood pressure monitors, i.e., due to the manual simulation of information on the LCD with plastic cards.

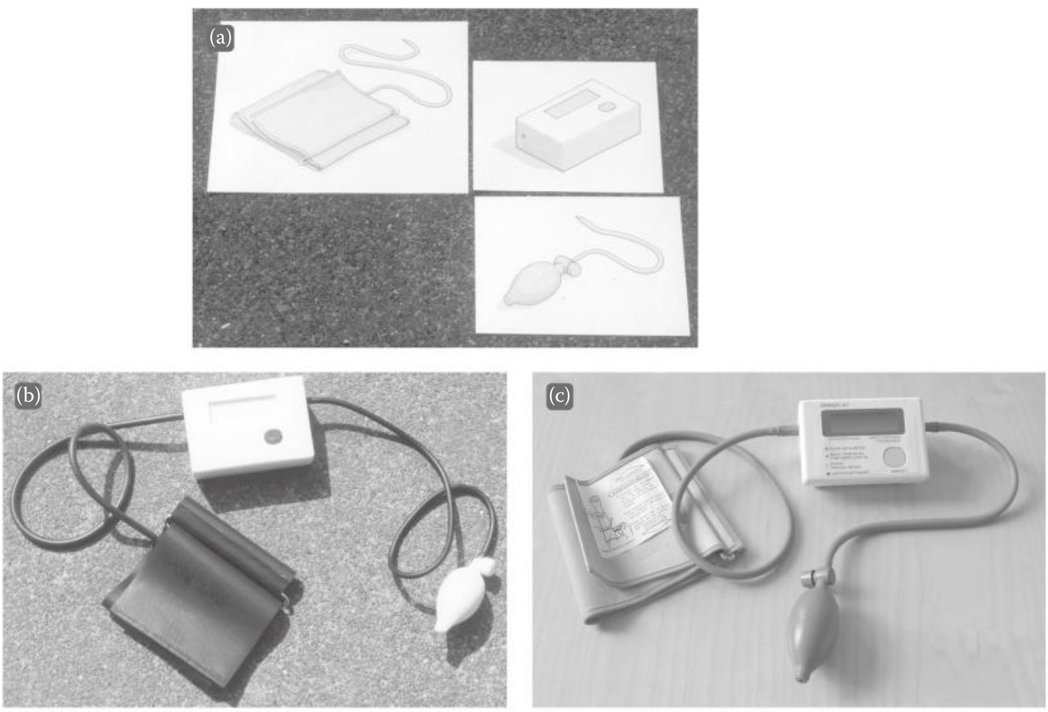


FIGURE 27.4 Three design models of the OMRON M1 blood pressure monitor: (a) a set of drawings, (b) a foam model, and (c) a final appearance model. The foam model was built from a variety of materials, apart from foam consisting of plastics, metal, and rubber. The final appearance model was created by removing the batteries and by blocking the hoses. With all models the information on the LCD was simulated with plastic cards.

27.2.2 Participants, Setting, and Procedure

Adult participants ($n=36$) were drawn from a household panel without further selection criteria. The participants were invited to our usability laboratory, which was considered an appropriate environment for the trials, resembling a living room with recording equipment out of sight.

The participants were randomly assigned to four situations. Three groups of nine participants went through two trials, first operating one of the design models, and then using the real blood pressure monitor. One group only used the real blood pressure monitor. The set up of the study allowed for both intra- and inter-individual analysis. The number of nine participants per situation was considered to be a good balance between capturing variety in usage, while collecting a still manageable amount of data for in-depth analyses.

Participants were welcomed and given an introductory talk, which included a brief explanation of the basics of measuring blood pressure. They were then asked to measure their blood pressure by using the real product or by operating one of the design models as if these were functioning in as far as possible.

Use actions were recorded on video. Information about sensory perceptions and cognition was elicited via thinking aloud and retrospective interviewing. While carrying out the actions, participants were asked to articulate their perceptions and thoughts; occasionally a reminder to do so was given. The videotaped operations were reviewed together with the participants. They were invited to make comments, and questions were asked to clarify what happened on the tape.

27.2.3 Data

For the study, the data are extracted from the observed and reported user activities with the design models as described in the transcripts of the trials. In total, there were 30 instances in which participants made remarks related to the model-status of the stimuli both during usage and during the review of the recordings.

A number of 30 instances seems limited. Of note is that the events of interest for this study were not actively elicited by the test leader. Participants made their remarks mostly spontaneously. Occasionally, utterances were triggered indirectly such as by discussing matters in the retrospective interview. In this chapter, 13 examples are highlighted. This number suffices to cover the encountered variety of participants' approaches.

27.3 FINDINGS

Distinctive interpretations of the models are presented, including their consequences as to the imagined functioning of the inferred design, i.e., as a match or a mismatch. Contextual information is supplied for each example. In addition, which aspect of the interaction and which design model were involved in the occurrence of a match or a mismatch is indicated.

1. Participants do not perceive the design model as a representation

By not perceiving a design model as a representation of something else, interactions do not get off the ground.

Example 1: context: on/off button, foam model (see Figure 27.5)
"... that round, it did not have any meaning to me."

Explanation: During usage, this participant does not operate or mention anything about the black round. She further remarks retrospectively that had graphics "on/off" been added on the model, she would have recognized it as a button.

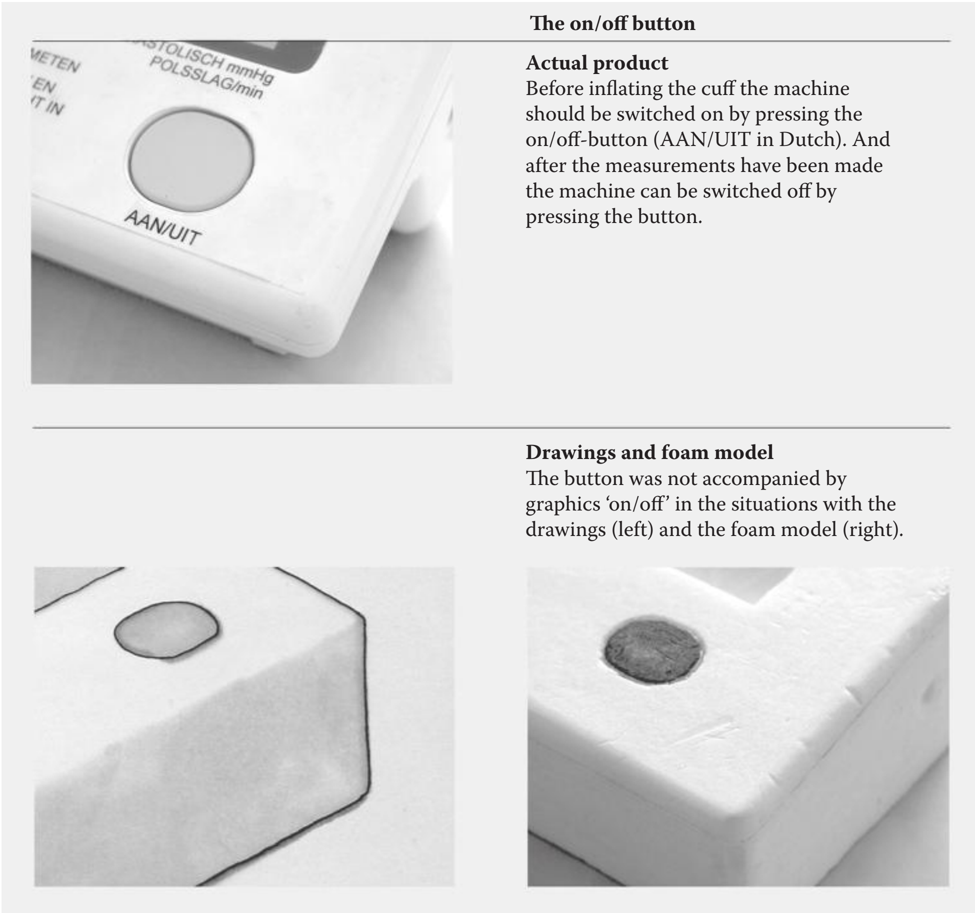


FIGURE 27.5 The on/off button on the real product and represented in the drawings and the foam model.

2. Participants perceive the design model as a representation, the characteristics of the design model are taken as they are

In most cases, participants perceived the design model as a representation of a blood pressure monitor. In a number of cases, they took the characteristics of the design models as they were, sometimes resulting in a match with the actual blood pressure monitor, sometimes in a mismatch.

Match

Characteristics, such as dimensions, graphics, or visual feedback on the display, can be accurately represented in the design models. When participants took these characteristics as they are, the interactions involved were relevant to learn about the envisioned design. These straightforward appreciations of the design models (i.e., assuming that the scale of the foam model is 1:1) tend to proceed without being mentioned and are not addressed in participants' verbal reports. Hence, no such examples are included in this chpater.

Mismatch

In the following examples, participants do not realize that some characteristics of the design model differ from those intended in the design.

Example 2: context: Velcro, foam model (see Figure 27.6)

"A bit difficult. That is not correct of course. It should be pulled tight. Let's see, that doesn't work. So. Well, that is a difficult case. Should be pulled tight somewhere. Anyhow, there is a hole here. Why is there such a thing? With one action it should be okay. And then you have to pull it tight, but I can't make it. I have to loop it through here, but that doesn't work. That is unclear to me."

"It was the case that I was approaching it as a sort of a buckle. ... I did not see anything else."

Explanation: This participant experiences difficulties because she expects the fixation mechanism in the model to be an accurate representation of the intended design. Her association with a buckle may prevent her from projecting Velcro on the cuff.

Example 3: context: Velcro, foam model (see Figure 27.6)

"I miss something one way or another. Because when I am going to inflate the cuff, it will come loose," says a participant during the trial.

"This is what I missed," exclaims the participant in the retrospective interview, when seeing the Velcro on the real product.

Explanation: This participant does view the model as a representation of a blood pressure monitor, and her assessment of the interaction is guided by her imagination of what would happen when the blood pressure monitor would be really functioning. She does not attempt to fill in the specific imperfection (lack of a fixation mechanism). When she remarks that she misses something, it is not clear whether she thinks that the model is not a one-to-one representation of the design or that the design itself doesn't meet her expectations.

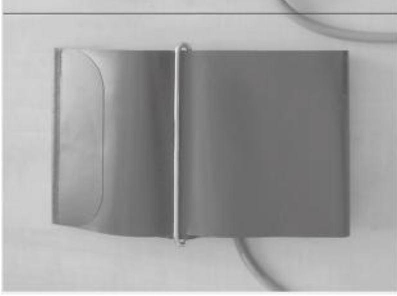
Example 4: context: sockets, drawings (see Figure 27.7)

"But that [the pump] should be connected, but I don't see anything. There is no socket, there is only one socket."

Explanation: Because he sees only one socket, this participant draws the conclusion that there is only one socket.

The cuff

Actual product
The cuff can be fixed around a variety of arm thicknesses by means of Velcro.



Foam model
Velcro was lacking on the cuff of the foam model.

FIGURE 27.6 The cuff. The actual version and the representation in the foam model.

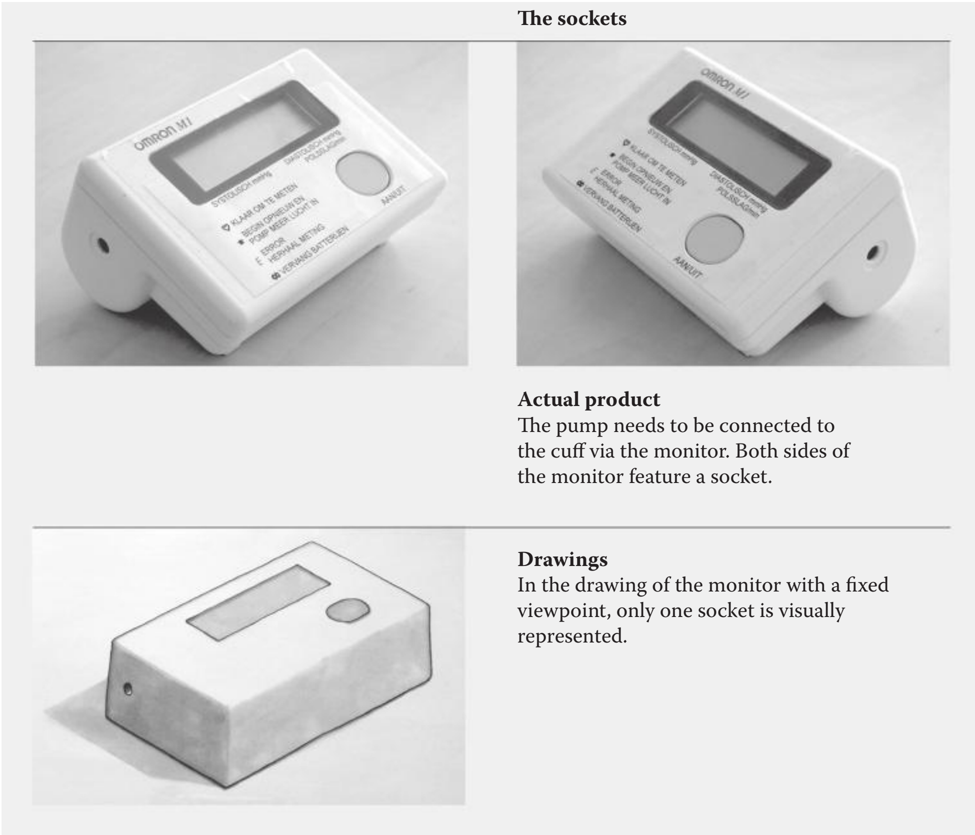


FIGURE 27.7 The sockets. The actual situation and the representation in the drawings.

3. Participants perceive the design model as a representation, a product is imagined by filling in and modifying characteristics of the design model

In most cases, participants perceived the differences and incompleteness of the design models. They imagined a real product on the basis of models of the blood pressure monitor by filling in and modifying characteristics. Two different ways of completing the design models could be distinguished: (a) on the basis of prior experience, and (b) on the basis of reasoning.

3a. Participants imagine a product on the basis of prior experience

Prior experience with product interactions was an important source of information in imagining a functioning product on the basis of the design model, sometimes resulting in a match with the actual blood pressure monitor, sometimes in a mismatch.

Match

Examples 5–7: context: pump, drawings, and foam model (see Figure 27.8)

"Well, that, I think, everyone will see that, because you see that at the doctor's as well."

"And this can also be found on scent bottles for spraying."

"From experience, because I have used such a thing at our laboratory to pipette acid, and because I have seen it at the doctor's." (Various participants)

Explanation: The participants recognize this part of the model as a pump, and imagine it to be squeezable. The recognition comes from experience with blood pressure monitors or with other

The pump

Actual product
The cuff is inflated by squeezing the pump; decreasing the volume inside the pump forces air through the hose to the cuff.

Foam model
The pump was simulated by a solid volume of foam, which could not be deformed by squeezing

FIGURE 27.8 The actual pump and the representation in the foam model.

products. Apparently, the rigid representation of the pump does not elicit deviating associations in these examples.

Mismatch

There were also instances that expectations about the design, based on prior experience, resulted in an imagined blood pressure monitor different from the real one.

Example 8: context: sockets, drawings (see Figure 27.7)
[Test leader: "You are looking for a connection between pump and cuff?"]
"Yes, that is what I know from practice in the past. Then the mechanism for pumping was sort of pushed into the cuff."

Explanation: Experience plays a role in locating the non-visible socket: the pump is directly connected to the cuff.

Example 9: context: on/off button, drawings (see Figure 27.5)
"I didn't look for an on/off-button, because with a mercurial meter switching it on is not needed."

Explanation: Participant's assumptions, based on experience with mercurial meters, results in a blood pressure monitor different from the design represented by the model.

3b. Participants imagine a product on the basis of reasoning

In some cases, participants did not refer to information from prior encounters with similar interactions, but showed knowledge-based behavior (cf. Rasmussen 1983).

Match

With knowledge-based reasoning, participants succeeded in interpreting the characteristics of the design model correctly with relevant interactions as a result.

Examples 10–12: context: on/off-button, drawings and foam model (see Figure 27.5)

[Test leader: "Why did you assume that to be the button to switch the monitor on?"]

"Yes, there obviously has to be a button to switch it on, and that button is located on the front. It is not located on the sides, so it should be a visible button, so that one is the button to switch it on."

"Because I did not see any other things for switching it on and off."

"It was the only button." (Various participants)

Explanation: Participants wanting to switch the monitor on perceive the representation as a button and indeed operate it by pushing.

Mismatch

Some participants completed the model on the basis of logical reasoning, however, with a result that did not correspond to the actual blood pressure monitor.

Example 13: context: the sockets, drawings (see Figure 27.7)

"I assume that this [the pump] should go here [the cuff], because the cuff is inflated, that's where air is pumped into."

Explanation: With a second socket not visible on the drawings, the participant opts for projecting a socket on the hidden sides of the drawings. A logical solution is then assuming a socket on the hidden side of the cuff, connecting the pump directly to the cuff to inflate it (most direct way to get air from pump to cuff) with the cuff connected to the visible socket in the monitor. The participant seems to reason by trying to understand the functional properties of the design.

27.4 CONCLUSIONS AND DISCUSSION

The explorative study described in this chapter shows a variety of ways in which design models are approached, resulting in a variety of imagined products (see Figure 27.9).

Figure 27.10 organizes the observed ways in which prospective users appear to interpret various aspects of the design models.

As shown, interpretations of prospective users may result in imagined products that match or mismatch the actual design. About half of the examples presented involve matches, the rest mismatches. As indicated above, the appreciation of model characteristics, e.g., as they are, may go

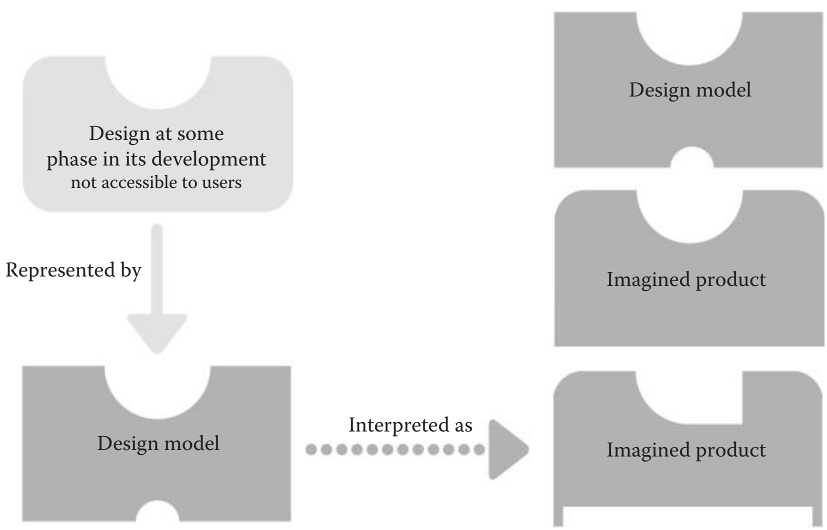


FIGURE 27.9 Users' interpretations of design models. The imagined products shown are examples from a variety of possible imagined products.

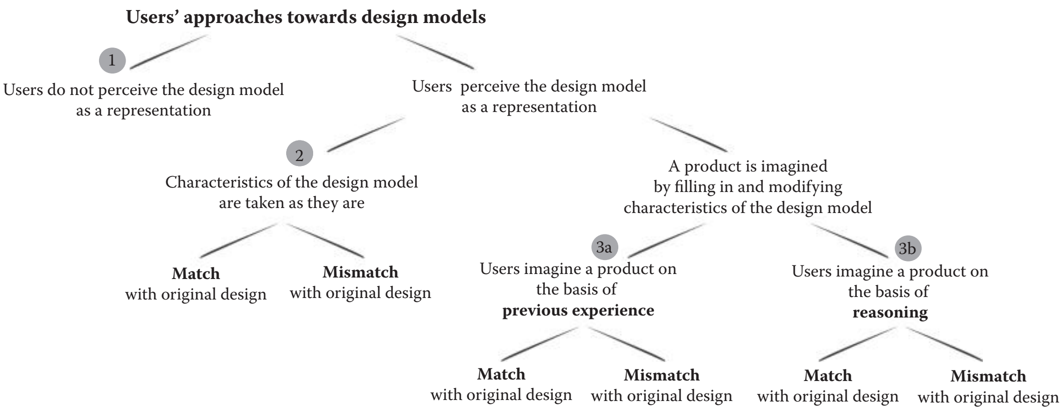


FIGURE 27.10 Participants' approaches toward design models. These approaches can bear on the design model as a whole, or on specific characteristics of the models. The numbers refer to the section of findings in which the examples are presented.

without saying. The same applies for obvious interpretations such as blood pressure meters not being made out of foam. In this respect, mismatches are clearly overrepresented in the verbal data and the presented examples. In fact, early user trialing is based on the justness of taking model characteristics for what "they are worth." The tenability of this approach is not addressed in this chapter. Here, the message of the present study is to be cautious in taking participants' interpretations for granted.

When expectations do match the actual design, the interaction with the model is relevant in learning about interactions with the actual blood pressure monitor. Cases of mismatch deserve special attention, because these may lead to "artificial" interactions, i.e., interactions that will not happen on the basis of the actual design. Making design decisions on the basis of these artificial interactions may lead to a suboptimal product. Therefore, in design processes it is important to know whether observed interactions emerge from "misinterpretation" of the characteristics of a design model or indeed from designed characteristics of an intended product. Here, an active approach of thinking aloud (cf. Buur, Bagger, and Binder 1997; Tamler 1998) seems indispensable in fully understanding how participants imagine a product on the basis of a design model. A drawback of this approach is that it may compromise the opportunity to observe natural usage.

27.4.1 Prior Experience and Reasoning

Two mechanisms can be distinguished in which participants imagined the design models as a functioning product. (1) Using information from prior experiences appeared to be important. People tried to copy what they knew from supposed similar interactions. This was successful when the intended design corresponded with their experience. (2) Information from reasoning, in trying to figure out product characteristics and supposed interactions by understanding the functioning of the product or by making logical deductions. As long as the designed interaction followed from the functioning of the device or had a logical rationale, prospective users were able to "guess" the interaction and compensate for any incompleteness or provisional characteristics of the design model.

Rasmussen (1983) argues that only when skills or application of learned rules fail, people will resort to knowledge-based behavior (see also Kirlik 1995). Our study can be seen to reflect this tendency. Prior experience indeed seems to play the most important role, with participants resorting to reasoning when they could not draw on information from prior experience.

27.4.2 Implications for Design Practice: Constructing Design Models and User Trialing

The insights into interpretations of design models by prospective users may be helpful in deciding which characteristics should be minimally represented in design models for user trialing:

- One should represent those characteristics that cannot easily be filled in by experience. Allocating these characteristics is complicated by the fact that a variety of prospective users will draw from a large variety of experiences. New, innovative, or rare design solutions should at least be tested by having them represented in the design model.
- When the designed interaction does not follow from the functioning and is without (or compromises) a logical rationale, it should be represented in the design models.

When performing user trials with design models, it is essential that the test leader is aware of the variety of approaches of prospective users toward design models. During a trial, he or she can then adequately ask for an explanation in order to understand user activities, and to evaluate the design relevance of the observed activities.

REFERENCES

Buur, J., Bagger, K., and Binder, T. 1997. Turning usability testing into user dialogue. In *Proceedings of the 13th Triennial Congress of the International Ergonomics Association*, eds. P. Seppala, T. Luopajarvi, C.H. Nygard, and M. Mattila, vol. 2, 132–34. Tampere: Finnish Institute of Occupational Health.

de Bont, C.P.M. 1992. Consumer evaluations of early product concepts. Thesis, Delft University Press.

Fay, D., Hurwitz, J., and Teare, S. 1990. The use of low-fidelity prototypes in user interface design. In *Proceedings of the 13th International Symposium on Human Factors in Telecommunications*, 23–31. HFT, Torino, Italy.

Kirlik, A. 1995. Requirements for psychological models to support design: Toward ecological task analysis. In *Global Perspectives on the Ecology of Human-Machine Systems*, eds. J.M. Flach, P.A. Hancock, J.K. Caird, and K.J. Vicente, 68–120. Hillsdale, NJ: Lawrence Erlbaum Associates.

Moggridge, B. 2007. *Designing Interactions*. Cambridge: MIT Press.

Norman, D.A. 1983. Some observations on mental models. In *Mental Models*, eds. D. Genter and A.L. Stevens, 7–14. Mahwah, NJ: Erlbaum.

Prümper, J., Heinbokel, T., and Kuting, H.J. 1993. Virtuelle Prototypen als Werkzeuge zur benutzercentrierten Productentwicklung. *Zeitschrift für Arbeitswissenschaft* 47 (3): 160–67.

Rasmussen, J. 1983. Skills, rules, and knowledge: Signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems and Cybernetics* SMC-13 (3): 257–66.

Rooden, M.J. 2001. Design models for anticipating future usage. Thesis, Delft University of Technology.

Rooden, M.J., Green, W.S., and Kanis, H. 1999. Difficulties in usage of a coffee maker predicted on the basis of design models. In *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*, 6-941–44. Houston, Texas: HFES, Santa Monica, California.

Tamler, H. 1998. How (much) to intervene in a usability session. *Common Ground* 8 (3), 11–15.

Virzi, R.A., Sokolov, J.L., and Karis, D. 1996. Usability problem identification using both low- and high-fidelity prototypes. In *CHI Conference Proceedings Human Factors in Computing Systems*, eds. M.J. Tauber, V. Bellotti, R. Jeffries, J.D. Mackinaly, and J. Nielsen, 236–43.

Wiklund, M.E., Thurrott, C., and Dumas, J.S. 1992. Does the fidelity of software prototypes affect the perception of usability? In *Proceedings of the Human Factors Society 36th Annual Meeting*, 399–403. Atlanta, Georgia: HFS, Santa Monica, California.

28 Eco-Design: The Evolution of Dishwasher Design and the Potential for a More User-Centered Approach

Elies Dekoninck and Edward W. A. Elias

CONTENTS

28.1 INTRODUCING ECO-DESIGN

Tischner and Charter (2001) present a simple model (Figure 28.1) of the relationships between product design, eco-design, sustainable design, and sustainable development. Product design is taken as an important starting point and they describe how product design largely determines the environmental and social impact of a product. Eco-design is the integration of environmental considerations and the life cycle perspective into product design and development. Sustainable design goes one step further and integrates social and ethical aspects of the product's life cycle. These three approaches form the link between production and consumption and therefore have pivotal roles to play. Sustainable development is the outermost ring and is based on the Brundtland (1987) definition of sustainable development, to "meet the needs of a current generation without compromising the ability of a future generation to meet their needs."

There are several commercial benefits of using eco-design and developing environmentally sensitive and sustainable products, including reduced manufacturing overheads, reduced material and energy use, reduced waste generation, an improved corporate image, and greater consumer loyalty. In markets where consumers are particularly aware of the environmental impact of the product, eco-design can be a competitive advantage and major sales focus. In 1998, Philips launched a range of "green products" (Philips Electronics 1998) and has long viewed environmental care as a business opportunity, where the corporate "Green Image" is of great value to the company both externally and internally (Meinders 1999). This competitive advantage can also be clearly seen in the automobile industry, where companies with an environmentally proactive approach have moved from strength to strength while others have suffered.

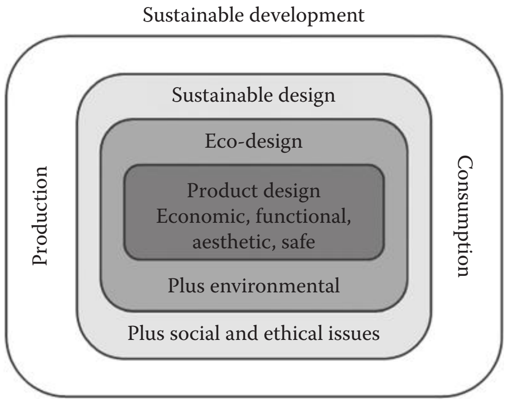


FIGURE 28.1 Eco-design and sustainable development. (After Tischner, U. et al., *How to do EcoDesign? A Guide for Environmentally and Economically Sound Design*, Verlag Form Praxis, Germany, Frankfurt am Main, 2000.)

Popular "green" cars such as the Toyota Prius, which incorporates highly innovative technologies, have appeared to the consumer as an incremental step from a traditional car and have thus been more readily accepted than the more radical jump to the all-electric car. This suggests that although an eco-innovation methodology may deliver more environmental benefits, they also often require a behavioral change in consumers. Many companies may therefore select an incremental eco-design strategy.

This case study shows examples of both incremental and radical solutions to reduce the environmental impact of dishwashing and discusses how user-centered design approaches may deliver radical solutions that consumers will accept.

28.2 ENVIRONMENTAL IMPACT OF A DISHWASHER

The chosen product for this study is the domestic dishwasher. When studying the environmental impact of any product, process, or service, it is essential to look at the complete life cycle, from the extraction and formation of materials right through manufacture, delivery, use, and disposal. This study focuses on the main environmental impact for dishwashers, the use stage. The European Commission's eco-label for dishwashers, which focuses on "energy and water use" during the use stage, indicates that this element of its life cycle contributes the largest environmental impact (Bjerregaard 1998).

The automatic domestic dishwasher is an established product and is commonplace in many modern homes. The continued success of this product is, in part, due to the improved performance of the product; some machines can now claim to be more energy and water efficient than washing dishes by hand. A supporting factor for the success of this product is a social one; the increase in the number of families where both partners work means that time for domestic cleaning has decreased and their disposable income has increased.

In 1995, a major study was carried out that described the long-term efficiency targets for domestic dishwashers (van Holstein & Kemna 1995). This report suggested many design strategies for the environmental improvement of the dishwasher. These strategies were analyzed in terms of "increased cost" vs. "payback time." Strategies that achieved a payback time within the product lifetime are preferable; these are design solutions where the financial savings generated from the reduced energy and water use save more money over the product's lifetime than it cost to incorporate the extra technology and changes. However, studying the dishwashers launched in the late 1990s, it is noticeable that a number of machines sport environmental features that probably do not achieve a payback time within the product's lifetime. This can be explained by consumer demand for machines that achieve a high eco-label status, irrespective of the extra costs incurred.

Southcorp Appliances, now part of Electrolux, took part in the EcoReDesign program developed by RMIT to enhance its' expertise in dishwasher design (Gertsakis, Lewis, and Ryan 1997). They undertook studies into life cycle analysis, design for disassembly, recycling, and strategic product development. This best practice case study highlighted the most important design issues for dishwashers—maximizing energy and water efficiency—and resulted in the development, design, and launch of the Dishlex Global Range dishwashers, which were awarded the appliance industry award for the best white-good in 1997. Electrolux sees the environment and eco-design as an important part of its' corporate image and a strong driver for product improvement. Having won numerous awards for corporate commitment to the environment and energy- and water-efficient environmental design, most recently the European Commission's 2007 Sustainable Energy Award in Corporate Commitment Category.

28.2.1 Efficiency Improvements

The first commercial dishwasher, a hand-operated mechanical device, went on sale at the 1893 Chicago World Fair. It was not until the 1970s that domestic dishwashers became commonplace in many homes. Since that time, the design has evolved incrementally with considerable improvements in energy efficiency, water usage, and product performance.

Information from Waterwise, a UK non-government organization (NGO) focused on decreasing water consumption, shows that dishwasher ownership among UK households has risen from less than 5% in 1977 to over 33% in 2006, with dishwasher use having stayed static over the past 15 years at an average of 4 times a week per household.

In the past 30 years, water efficiency has risen by over 60% from an average of over 50 L per wash in the 1970s to an average of 15 L per wash today. The amount of water and energy used are directly related; the van Holstein & Kemna (1995) report makes clear that eco-design improvements that reduce energy usage tended to have the fastest payback, due to the relative costs of electricity when compared to water and detergent. The main motivation to reduce the volume of water used is to obtain a reduction in heating energy required for that volume. Waterwise (2006) believe that this increase in efficiency is likely to continue in the next few years with further potential savings of water of 50%.

Hand washing can be very efficient if you use a bowl and watch how much water you use. But daily hand washing typically uses about 63 L and if dishes are rinsed off under a running tap the total water used can be 150 L. A modern dishwasher washing an equivalent amount can use as little as 10 L of water per wash cycle. The rise in dishwasher ownership and the increases being made in efficiency have led to an overall reduction in the amount of water used for washing up (Market Transformation Programme 2006).

Energy efficiency is measured by the U.S. Environmental Protection Agency and rated on a system called the Energy Factor, which is the number of wash cycles per kilowatt-hour of electricity and is set at 0.46. An "Energy Star" rating is achieved if the appliance performs better than a set target. In 1997, this target was for a 13% improvement above the Energy Factor (0.52), in 2001 it was raised to 26% (0.58), and currently it stands at 41% (0.65). Many companies see the Energy Star as an essential product specification and almost no manufacturers, selling into the USA, produce goods that do not meet or exceed this target.

From the 44 manufacturers listed in Table 28.1, only four sell any models that do not achieve an Energy Star rating, six exceed the rating by more than 96%, and one exceeds the standard by 181%, these have been highlighted in Table 28.1 for clarity. Equator produce a series of eight models that achieve this high 181% Energy Star rating, each claiming to clean eight place settings with an estimated 166 kWh/year. A factor that is not considered by this data when looking for the most energy efficient dishwasher is product quality and cleaning ability. A poor cleaning product only suitable for light loads may be commercially attractive because of a high energy score. The available information about the Equator models suggests that this may be the case; they are half-sized counter-top

TABLE 28.1
U.S. Environmental Protection Agency Energy Star Dishwasher Ratings 2007

		Energy Factor (% Better)		
Brand	**No. of Dishwasher Models**	**Average (%)**	**Best Model (%)**	**Worst Model (%)**
Equator	18	107.4	181	41
Asko	29	93.6	159	56
Viking	7	88.6	102	62
Dacor	2	76.0	76	76
Ariston	6	74.0	74	74
Fisher & Paykel	2	68.5	97	40
Danby Designer	2	67.0	67	67
Haier	3	62.7	70	48
Gaggeneau	4	61.0	61	61
LG Electronics	4	60.0	63	59
Eurotech	6	57.2	61	43
Thermador	6	56.7	61	48
Siemens	22	54.5	72	48
KitchenAid	6	52.5	97	40
Bosch	79	50.8	61	48
Electrolux	3	50.0	50	50
Silhouette	1	50.0	50	50
Smeg	4	49.0	50	48
Miele	21	48.1	50	41
Sharp	1	48.0	48	48
Frigidaire	52	47.3	57	43
Blomberg	25	47.0	47	47
Inglis	2	47.0	53	41
Profile	16	46.4	50	40
Kenmore	62	46.2	110	41
Monogram	7	46.1	59	40
Gibson	2	46.0	46	46
General Electric	31	45.9	56	43
Whirlpool	35	45.2	48	41
Eterna	3	45.0	46	43
Estate	2	44.5	48	41
Roper	2	44.5	48	41
Adora	5	44.2	46	43
Fagor	10	43.0	43	43
Heartland	4	43.0	43	43
Sunbeam	7	43.0	43	43
Hotpoint	6	41.7	43	41
Amana	3	41.0	41	41
Americana	1	41.0	41	41
Crosley	1	41.0	41	41
Ikea	1	41.0	41	41
Jenn-Air	8	41.0	41	41
Maytag	25	41.0	41	41
White-Westinghouse	1	41.0	41	41

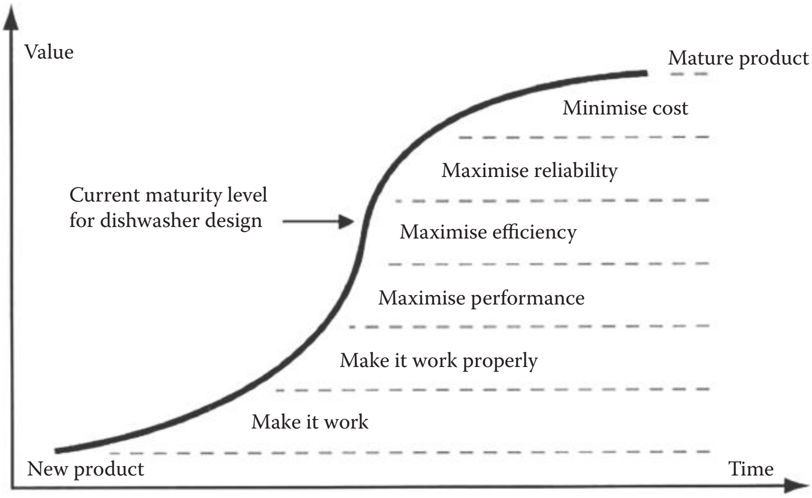


FIGURE 28.2 Typical invention focus S-curve. (After Mann, D. 1999. *TRIZ Journal* online [July]. http://www.trix-journal.com [accessed May 8, 2007].)

models, designed for small home or office use and are at the low end of the price spectrum. Other Equator products resemble the typical floor standing, single-door dishwashers of other manufacturers and have an energy score of 41%.

28.3 DESIGN MATURITY

The maturity of a design typically follows an S-curve model where the customer experiences relatively low value when the product is introduced. However, over time, companies continue to improve their product to maturity. Figure 28.2 lists the focus of the design activity at the various stages of the curve. Many new dishwasher products focus on maximizing efficiency by reducing water and energy consumption, suggesting a mid-level maturity of the current design. Innovative new thinking can create radically new dishwasher concepts and a second product S-curve could be initiated (Figure 28.3). The new innovation curve will continue to rise as the previous one begins to plateau, eventually the value that consumers experience from a new technology will overtake the previous design.

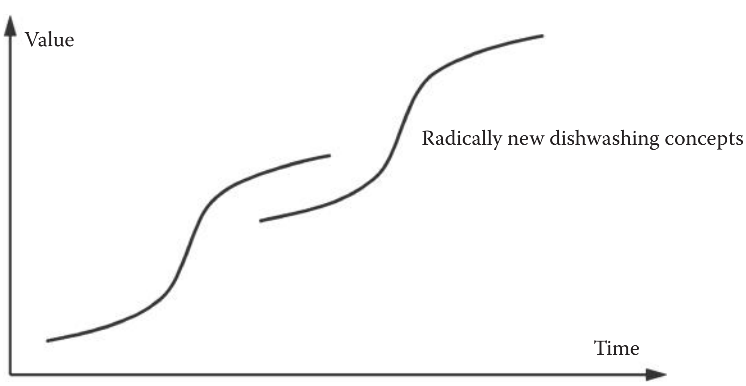


FIGURE 28.3 Successive S-curves, an innovation jump to new dishwasher design.

At the start of each S-curve there will be evidence of a varied collection of possible product ideas. As time progresses, technical and commercial forces select the strongest to continue and a time of rapid innovation follows as performance and efficiency is improved.

Table 28.2 shows a study of U.S. patents from 1975 to 2006 relating to dishwashers, providing an overview of the evolution of dishwasher design and gives a useful guide to technology maturity. Table 28.2 shows evidence of the second S-curve starting to take shape, new designs involving dishwashers integrated with dining tables, sinks, or double front loading are starting to be designed and making their first appearances in the patent database. For clarity, these patents have been grouped into Table 28.3.

28.4 PRODUCT-CENTERED VERSUS USER-CENTERED INNOVATION

The van Holstein and Kemna (1995) report states the main factors affecting the effectiveness of automatic cleaning of dishes are: time, temperature, detergent, and mechanical action. However, the report also specifies that at a given volume and composition of the total wash load per period of time (per week/year), the environmental efficiency of the dishwasher will depend on the following three parameters:

1. Consumer behavior
2. Machine-dependent variables
3. Parameters that depend on the energy/infrastructure supply

It is clear from the patents studied in Table 28.2 that very few focus on the first parameter: consumer behavior. The machine-dependent variables can be broken down further into four factors: increasing the product lifetime, reducing detergent usage, reducing water usage, and reducing heating energy. Figure 28.4 lists some of the solutions patented under those design strategies.

This case study shows that most of the eco-design work has gone into reducing the water usage and heating energy, including infrastructure and system changes as this represents 90% of the energy consumed by the dishwasher (Columns 2, 5, and 6 from figure 28.4).

Another major factor influencing the efficiency of the machine is its usability (Table 28.2, column 1). As a requisite for the eco-label, companies need to encourage responsible user behavior by including special instructions for the optimal use of their product. Manufacturers have focused on: improving the stacking efficiency, ease of maintenance to prevent breakdown, and the optimization of the wash programs offered. Figure 28.5 shows how the companies innovation efforts to date have focused predominantly on product-centered solutions (columns 3–6), as opposed to user-centered solutions (column 1). Column 2 highlights infrastructure and systems changes that fall between the product and the user and could see benefits to each.

28.5 POTENTIAL FOR USER-CENTERED ECO-DESIGN

User-centered design is design that is informed and guided by studies of human behavior, product use, and ergonomics, making the use of products more intuitive and in keeping with the user's lifestyle. The overall objectives of ergonomics and human factors are to optimize the effectiveness and efficiency with which human activities are conducted as well as to improve the general quality of life (Stanton 1998). Combining this approach with eco-design presents the possibility of creating products where the most intuitive and comfortable way of using and interacting with a product or system is also the most environmentally friendly.

In general, activities in the field of eco-design have, to date, predominantly focused on reducing the impact of manufacturing and disposal, a focus that is arguably driven, in part, by legislative demands. With the exception of safety and manufacturer liability, there appears to be a lack of consideration on the part of manufacturers and designers for the effects of product use (Lilley, Lofthouse,

TABLE 28.2
Patent Collection of Dishwashers Studied

			Make it Work	Make it Work Properly	Maximize Performance	Maximize Efficiency	Maximize Reliability	Minimize Cost
1975	US3923073	Means for heating incoming water in a dishwasher				x		
1978	US4070204	Low-energy dishwasher				x		
1978	US4097307	Fill control for an automatic dishwasher				x		
1978	US4128287	Household appliance with a base setback on the front side thereof			x			
1980	US4182351	Gentle cycle valve for digital dishwasher			x			
1980	US4221547	Resilient mount for dishwasher motor and pump assembly					x	
1981	US4246916	Dishwasher with steam-generating heater and cold water input				x		
1982	US4343349	Heat pipe device and heat pipe fabricating process			x			
1982	US4347861	Dishwasher soil separator				x		
1985	US4509687	Multiple spray distribution system				x		
1985	US4529032	Method of and apparatus for recovery of waste energy				x		
1985	US4531572	Method of and apparatus for recovery of waste energy				x		
1987	US4673441	Controlled inlet valve for supplying cleansing liquid into the sump				x		
1991	US4984596	Operating device for a dishwasher					x	
1991	US4998548	Self-cleaning filter for a dishwasher					x	
1991	US5016667	Device for a dishwasher			x			
1991	US5056543	Device for drying dishes in a dishwasher				x		
1992	US5129411	Liquid level control arrangement for a dishwasher				x		
1992	US5143306	Waste disintegrating device for a dishwasher			x			
1992	US5144543	Domestic appliance having electrically isolated input control circuitry					x	
1992	US5165433	Soil separator for a domestic dishwasher				x		

(*continued*)

TABLE 28.2 (Continued)
Patent Collection of Dishwashers Studied

			Make it Work	Make it Work Properly	Maximize Performance	Maximize Efficiency	Maximize Reliability	Minimize Cost
1993	US5223042	Washing process for an automatic dishwashing machine				x		
1994	US5274954	Dishwasher door control system			x			
1994	US5284523	Fuzzy logic control method for reducing water consumption				x		
1994	US5368379	Dishwasher chassis: a part of the shell comprising the bottom of the tub					x	
1995	US5386724	Device for a dishwasher door			x			
1995	US5413259	Device for automatic metering of powdered detergent			x			
1995	US5429146	Dishwasher connectable for single-phase AC current				x		
1995	US5429679	Method for operating a low energy domestic dishwasher				x		
1995	US5462348	Dishwasher utensil tray			x			
1997	US5595200	Dishwasher with vertically adjustable basket			x			
1997	US5601195	Basket with a movable divider for a dishwasher			x			
1997	US5655556	Dishwasher with a rotating spray agitator					x	
1997	US5687752	Dining table with integral dishwasher	x					
1998	US5725001	Dishwasher with a pH-controlled program pre-selection				x		
1998	US5839097	Electrical home appliance: system design concept	x					
1998	US5823211	Dishwasher					x	
1999	US5882096	Dishwasher fastening being less complicated, more cost effective, and better stability						x
1999	US5884821	Device for dispensing detergent, particularly for dishwashers					x	
1999	US5904166	Spray arm support for front-loading dishwashers					x	
1999	US5980006	Device for weight compensation of a front end door of a household appliance			x			

1999	US6001190	Reduced energy cleaning appliance				x	
1999	US6035471	Method for detecting impermissibly high scaling in a water-conducting domestic appliance					x
1999	US5934298	Combination sink and dishwasher	x				
2000	US6092540	Table top sink side dishwasher	x				
2001	US6289908	Double front loading dishwasher		x			
2001	US6196239	Dishwasher status indicator				x	
2002	US6448212	Laundry/dishwasher detergent portion				x	
2002	US6432216	Soil sensing system for a dishwasher				x	
2003	US6615850	Dishwasher sanitation cycle and temperature optimization			x		
2003	US6550488	Hyperwash high temperature dishwasher			x		
2003	US6571965	Dishwasher rack with pivotable fences				x	
2003	US6546942	Dishwasher with auxiliary basket				x	
2004	US6832618	Dining table with integral dishwasher		x			
2004	US6817367	Liquid containment system for a dishwasher				x	
2005	US6939412	Method and apparatus for sensing water flow through a dishwasher including a thermal sensor				x	
2005	US6869029	Water spray system for a dishwasher			x		
2005	US6966323	Gas-heated dishwasher	x				
2006	US7028697	In-sink dishwasher	x				

Note: Crosses indicate invention focus.

TABLE 28.3
Patents Showing Evidence of a New S-Curve

			Make it Work	Make it Work Properly	Maximize Performance	Maximize Efficiency	Maximize Reliability	Minimize Cost
1997	US5687752	Dining table with integral dishwasher	x					
1998	US5839097	Electrical home appliance: system design concept	x					
1999	US5934298	Combination sink and dishwasher	x					
2000	US6092540	Table top sink side dishwasher	x					
2001	US6289908	Double front loading dishwasher		x				
2004	US6832618	Dining table with integral dishwasher		x				
2005	US6966323	Gas-heated dishwasher	x					
2006	US7028697	In-sink dishwasher	x					

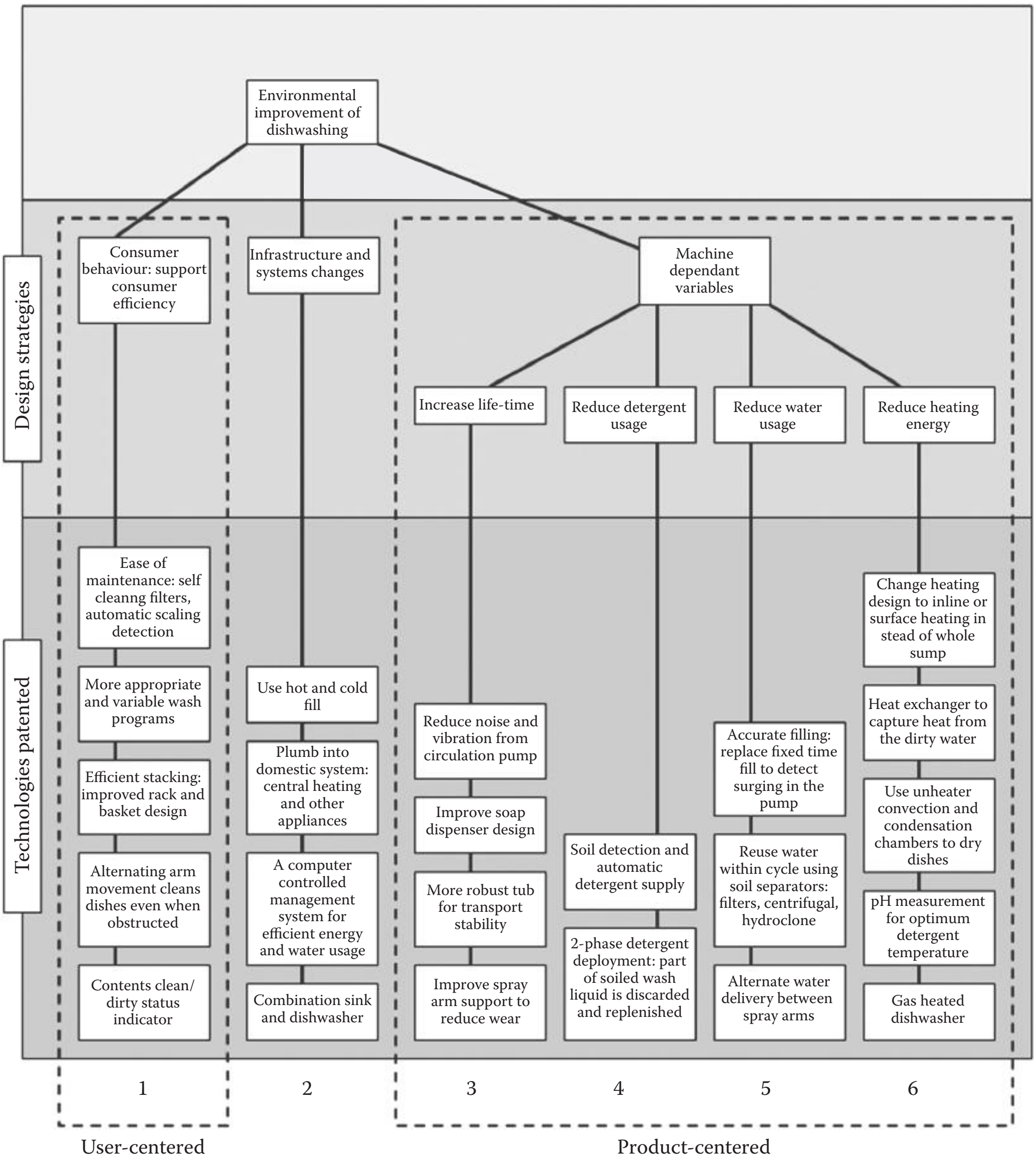


FIGURE 28.4 User-centered vs. product-centered improvements. (After Jones, E. et al., *Creativity and Innovation Management*, 10, 3, 2001.)

and Bhamra 2005). In dishwasher design, however, the energy in the use stage has attracted considerable attention from consumers and voluntary market standards, such as the Energy Star, has driven innovation in this area. The environmental and social impacts associated with the use phase, which are for the most part caused by the consumers' behavior, are significant (Environmental Change Unit 1997; Sherwin and Bhamra 1998). In dishwasher design there is little evidence that consumer behavior has driven the innovation effort to date.

Examples of other products where a user-centered approach has presented a more environmentally friendly result can be found with detergent tablets for washing machines, where research by Unilever found that users often used too much powder. The tablet counteracts this effect by providing the user with the correct amount, thus preventing excessive use (Unilever 2001).

FIGURE 28.5 The double DishDrawer from Fisher and Paykel (2007).

Electrolux trialed a new business model for clothes washing called "functional sales" in which they offered customers a pay-per-wash scheme, allowing customers to pay only for the function of clean clothes. Customers had a washing machine in their home without ownership. Paying for the number of usages creates customer incentives to reduce the number of washes, which may reduce the overall energy and detergent consumption. These new business models are growing in popularity in a number of different fields and have been called a product service system. More recently, these systems have developed into what is known as eco-efficient services. Eco-efficient services are all kinds of commercial market offerings aimed at fulfilling customer's needs by selling the function of a product instead of just the product (Meijkamp 2000). The design focus of these new business models is to increase product longevity and reduce maintenance requirements. They may also offer greater product responsibility from the manufacturer, providing environmental benefits at end-of-life.

This case study has shown that there is an opportunity to refocus the innovation effort to reduce the environmental impact in the use stage by producing products that work more closely with consumer behavior. This requires the study of consumers using techniques from human factors and using the outcomes to create new product concepts for dishwashers.

28.5.1 Current User-centered Product Concepts

Fisher and Paykel (2007) produce a product called the DishDrawer Dishwasher, with an Energy Star rating of 97%, which uses two independent dishwashing drawers in one unit, allowing the user to run two separate washes at the same time with different items in each, permitting greater control, flexibility, and efficiency. For example, a drawer of delicate glass can be washed at the most suitable wash cycle while also washing a draw of pot and pans on a heavy program.

The DishDrawer also caters for small loads. Each DishDrawer holds half the capacity of a conventional dishwasher, removing the need in a conventional dishwasher of running a dishwasher half full. This better suits new family demographics with more people living alone and the rise in the number of professional couples. Some users of the double DishDrawer model have begun to use their DishDrawer as the primary storage location for dishes and crockery, rather than having a separate kitchen cupboard.

In 2004, Electrolux ran a design competition where design students from leading schools in nine countries competed to create a new appliance concept. The students were challenged to design products for a daring but not too distant future. The design concepts were free from the constraints of tradition, but resulted from the students' in-depth research into consumer needs and innovative ideas on how to "make life a little easier." Henrik Otto, Global Head of Design at Electrolux, said "the unique appliance concepts developed by the students demonstrate the power of creating products directly related to consumer needs, these concepts and ideation will make a significant impact on our product and design innovation efforts" (Electrolux Global Design Lab Competition 2004).

The winning entry was a revolutionary new dishwasher called the Rockpool (2004), created by three FBE industrial design students. The Rockpool uses carbon dioxide in a supercritical fluid form, instead of water, to wash the dishes. On completion of a cleaning cycle the contaminants precipitate out into the household gray water management system and the CO_2 is returned to storage for repeated use. At room temperature, pressurized carbon dioxide turns into a supercritical fluid with the properties of both a liquid and a gas, it has no surface tension and dissolves grease and oils.

28.6 CONCLUSIONS

This case study has shown that over the last three decades considerable efficiency improvements have been made to dishwashers, to such an extent that cleaning dishes by hand can now practically be considered environmentally unsound. This progress has been largely achieved by a product-centered approach driven, at least in part, by energy labels. As the existing dishwasher design matures, the potential for further improvements will slow down. This case study shows that the next generation of dishwashers could be based on radically new concepts created by a user-centered design process. During this case study, a few examples of new dishwasher concepts that address user behavior were found, although no comprehensive study of consumers using dishwashers was uncovered. A comprehensive study of consumers is likely to show that there is great innovation potential to be driven from a user-centered approach, where consumers are studied using techniques from human-factors and used as a starting point for product innovation.

REFERENCES

Bjerregaard, R. 1998. Establishing ecological criteria for the award of the community eco-label to dishwashers. *Official Journal of the European Communities* 216:12–16.

Brundtland, G.H. 1987. *Our Common Future. World Commission of Environment and Development*. Oxford: Oxford University Press.

Electrolux. 2004. Electrolux Global Design Lab Competition (November), http://www.electrolux.com/designlab/ (accessed May 8, 2007).

Energy Star. 2007. Dishwashers. U.S. Environmental Protection Agency, U.S. Department of Energy, http://www.energystar.gov/ (accessed May 8, 2007).

Environmental Change Unit. 1997. *2MtC – DECADE: Domestic Equipment and Carbon Dioxide Emissions*. Oxford: Oxford University.

Fisher & Paykel. 2007. Kitchen appliances. Dishwashing, energy saving tips, http://www.fisherpaykel.co.uk (accessed May 8, 2007).

Gertsakis, J., Lewis, H., and Ryan, C. 1997. *A Guide for EcoReDesign: Improving the Environmental Performance of Manufactured Products*. Melbourne: National Centre for Design at RMIT.

Jones, E., Darrel, M., Harrison, D., and Stanton, N.A. 2001. An eco-innovation case study of domestic dishwashing through the application of TRIZ tools. *Creativity and Innovation Management* 10 (1): 3–14.

Lilley, D., Lofthouse, V.A., and Bhamra, T. 2005. Towards instinctive sustainable product use. *Presented at the 2nd International Conference: Sustainability Creating the Culture,* 2–4 November, Aberdeen Exhibition & Conference Centre, Aberdeen.

Mann, D. 1999. Using S-curves and trends of evolution in R&D strategy planning. *TRIZ Journal* online (July), http://www.trix-journal.com (accessed May 8, 2007).

Market Transformation Programme. 2006. BNW16: A comparison of manual washing-up with a domestic dishwasher. The Market Transformation Programme, UK.

Meijkamp, R. 2000. *Changing Consumer Behaviour Through Eco-efficient Services: An Empirical Study on Car Sharing in the Netherlands*. Delft, The Netherlands: Delft University of Technology.

Meinders, H. 1999. *Point of No Return. Philips Ecodesign Guidelines*. Eindhoven, the Netherlands: Philips Corporate Environmental & Energy Office.

Philips Electronics. 1998. *From Green to Cold Catalogue*. Eindhoven, the Netherlands: Philips Corporate Environmental & Energy Office.

Rockpool. 2004. Electrolux Global Design Lab Competition Winner, University of South Wales, Sydney, Australia.

Sherwin, C., and Bhamra, T. 1998. Ecodesign innovation: Present concepts, current practice and future directions for design and the environment. *Design History Society Conference*. Huddersfield, UK: University of Huddersfield.

Stanton, N. 1998. *Human Factors in Consumer Products*. London: Taylor & Francis.

Tischner, U., Schminke, E., Rubik, F., and Prösler, M. 2000. *How to do EcoDesign? A Guide for Environmentally and Economically Sound Design*. Frankfurt am Main: Verlag Form Praxis.

Unilever. 2001. Unit dose: A sustainability step for fabrics liquids. Prepared and issued by Unilever HPC, Europe, September.

van Holstein & Kemna. 1995. *Dishwashers: Long-term Efficiency Targets, A Technical and Economic Analysis*. Delft, the Netherlands: van Holstein & Kemna.

Waterwise. 2006. *Ranking of Dishwashers*. London, UK. http://www.waterwise.org.uk (accessed May 8, 2007).

29 User-Centered Design Method to Attend Users' Needs during Product Design Process: A Case Study in a Public Hospital in Brazil

Raimundo Lopes Diniz and Marcelo M. Soares

CONTENTS

29.1 INTRODUCTION

It is true that ergonomics and design are disciplines that almost always go hand in hand and generally lean toward the needs of human beings. According to Chapanis (1994), ergonomics is a body of knowledge about the abilities, limitations, and other human characteristics that are relevant to design. Karwowski (2005) states that ergonomics is a discipline that focuses on the nature of human–artifact interactions viewed from the unified perspective of the science, engineering, design, technology, and management of human-compatible systems, including a variety of products and processes, in natural and artificial environments. In this way, "ergonomic design" is the application of ergonomics in the design of tools, machines, systems, tasks, organization, and physical environments for the safety and comfort for effective human use.

Pheasant (2005) emphasizes that the aim of ergonomics is to achieve the best possible integration between the product and its users in the context of the work that is to be done. This considers that ergonomics is a discipline that seeks to adapt the work to the worker and the product to the user.

Soares (1999) points out that ergonomically well-designed products are those that consider a wide variety of users; the everyday and eventual user, the elderly, children, males, females, the healthy or unhealthy, while offering safety, efficiency, comfort, and aesthetic satisfaction under normal conditions of use and under foreseeable conditions of misuse.

The sometimes uneasy relationship between designers and ergonomists has been mentioned historically by several authors (Abeni 1988; Brown and Wier 1982; Grandjean 1984; Lingaard 1989; Pheasant 2005; Ryan 1987; Smith 1987; Ward 1990, 1992; Wood 1990). According to Meyer (1989) and Ward (1990), one of the main areas of conflict between product designers and ergonomists arises from the emphasis that each group places on the methodology employed to reach its objectives. Designers are always expected to be innovators, looking for a different solution to a problem by the way they work in a creative and intuitive manner, trying out a number of solutions and evaluating them later. Designers usually approach problems using what is called "lateral thinking," which means the use of creative thinking to solve problems, avoiding a too logical and too constrained conventional frames of reference approach. Ergonomists, although they sometimes use creative techniques, tend to analyze the problem and develop formulae or experiments that will deliver what they regard as the answer or best solution.

As previously cited, the authors recognize frictions between ergonomists and product designers and unanimously agree that this disagreement needs to be overcome. The successful integration of ergonomics and product design will produce an aesthetically pleasing and functionally superior product (Kreifeldt and Hill 1976). Each is directed to the same end, fulfilling user satisfaction and the production of a successful product. Harris (1990) claims that because the world markets are composed of a multitude of anthropomorphic, behavioral, and cultural differences, ergonomic knowledge is vital in helping designers to meet the challenge of product development for a global market. Hence, the integration of ergonomics and product design seems to be particularly relevant when designing products.

The unique way to carry out a design process centered on the user is by applying ergonomic knowledge beginning early in the product development process. Such an approach has been supported historically by several authors, such as Cushman and Rosenberg (1991), Harris (1990), Kreifeldt (1984), and Ward (1990).

The design of products is an area in which the goal is to solve problems while considering the needs of human beings. The designer is responsible for developing project strategies that transform potential user needs into a project briefing. Guimarães (2004), using the research of Lobach (2000), states that during the product design development process the following functions are to be considered:

- Practical function—highlighted by functionalism and the relation of the use of the product by the user
- Esthetic function—sought by all artistic movements and related to the product's aesthetic quality
- Symbolic function—as shown in styling and in post-modernism when interpreting the aspirations of the public and coupling them with the product
- Ecological function—relating to the eco-efficiency of the product life cycle

Depending on the design briefing, ergonomics content can be entwined with one of the four basic functions. However, the practical function is the one that needs ergonomic support more. Essentially, the frequency of use is a primordial factor when defining the application of ergonomics in design, e.g., the more a user interacts with a product, the more the need for ergonomic input in the design.

To this end, both ergonomics and design work with particular methods and techniques to help in the success of the product development process. This chapter will discuss the application of an ergonomic design method applied to the design of furniture used by persons accompanying patients to hospitals in the city of Sao Luis, northwest of Brazil.

29.2 ERGONOMICS AND PRODUCT DESIGN: A USER-CENTERED DESIGN STRATEGY

A huge variety of methods and techniques can be applied in the development of consumer products. Cushman and Rosenberg (1991) defined consumer products as those designed for use by the general public, different from commercial products, which are those used to produce goods and services. The coherent application of those methods and techniques in design development (design strategy/management) must take the human element into consideration along with the machine element or the human-machine element (Stanton and Young, 1999). Generally, the design method is chosen in consideration of the objectives for the project's development, guided by the user profile, time and budget constraints, and other information from the design briefing.

Design and ergonomic methodologies possess a sequence of phases (or stages) with specific objectives, applied in several stages of the product development and aimed at solving specific design problems. Depending on the project objectives, each phase requires the application of techniques, which will be selected by the designer or the ergonomist. These techniques may have a qualitative approach (using tools that consider the perception/subjectivity of the subjects involved in the process, the potential users or the researcher/projector; e.g., interviews, observations, questionnaires, or verbalizations) or a quantitative approach (using tools that consider the variables without the interference of the perception/subjectivity of the researcher).

Generally, the design methodology includes the following phases:

- Conceptual—having as its objective the generation of design directives, design briefings, which enable proposals for the resolution of problems to be characterized while creativity in this case is the guiding factor.
- Configurational—elaboration of the manufacturing specifications of the product, dimensions, material, components, etc., and the creation of mock-ups, models, and prototypes so that the proposal can be physically evaluated and tested
- Marketing—introducing the product to the market
- Re-use—discarding components at the end of the product life cycle.

Usually, the design methods allow for feedback so that there can be a reorientation of the direction of the design and even modifications in the design proposals.

The ergonomic method considers the human being's characteristics, such as capacities, abilities, aptitudes, and limitations, during the design phases or at some stage in the life cycle of the product. According to Moraes (1992), in the development of products, ergonomics should be seen as the core of the project and not as a support tool. It must be emphasized that the ergonomic design is an opportunity for ergonomic innovations in the configuration and presentation of products and that of informational components. The ergonomic method follows a systemic and systematic development with the following phases:

- Investigating the product problems—gives the design team a basis to decide what to do and how to do it.

- Ergonomic diagnostic of the product—involves finding the information directly relevant to the designers' further activities of generating and selecting feasible solutions to the creation of new product models. This phase includes the application of some tools, such as task analysis and subjective methods, which include surveys and interviews.
- Design and test of ergonomic solutions—in this phase some solutions are presented and tested using models and prototypes.

Traditionally, ergonomic methodology has a linear structure where each subsequent phase depends on the results of the previous one before it can be executed. This is different from design methodology in that ergonomics is less flexible in terms of interactivity (cycle process based on constant changes and refinements).

Ergonomics can be included at all stages of product development (Blaich 1987). The contribution of ergonomics in the process of product development includes (Cushman and Rosenberg 1991):

- Product planning: preparation of user portfolio, evaluation of initial concepts, participation in marketing research activities, reviewing the ergonomic literature, conducting ergonomic studies, and establishing ergonomic design objectives.
- Design: perform function allocation and task analysis, transform ergonomics data into a usable form, evaluate early prototypes and mock-ups, perform hazard analysis, and participate in writing technical specifications.
- Testing and verification: test prototypes with users, provide recommendations for design modifications, and provide recommendations for the revision of product documentation.

Generally, there are two paths to follow in the generation of a product that has ergonomics and design as its essence. One path, suggested by Blaich (1987), is the contribution of ergonomics at some specific phase of the design process. The other path is the application of design methodology within the ergonomic methodology during a phase called ergonomic design. It means that the ergonomic principles obtained in the phases of ergonomic methods are the foundation for the conceptual stage of the design, which generates the main design requirements.

Darses and Wolff (2006), while calling attention to a problem for the designer in applying ergonomics in the design process, suggest the use of ergonomics or participative design as an approach to efficiently integrate human factors information during the design process. According to the authors, the participatory design is currently seen as a promising approach that provides a holistic view of the design process and a broad conception of working conditions, as well as the application of specific methods, such as design games and scenario building.

The design and ergonomic juncture permits an interdisciplinary approach using characteristics and methods from both areas. This will result in the collaboration of all the participants in the product development process: designers, ergonomists, management, and finance and marketing personnel with the objective of evaluating the design process, product configuration, and application of the final proposal to the marketplace (Daniellou 2007).

Ergonomic principles applied to design may generate many improvements in the product, including better comfort, adequate dimensions, improved safety of use, ease of manipulation, minimization of force needed, rationalization and functionality of the physical arrangement of components, ease of maintenance, appropriation of visual field, better visibility and legibility of letters, numbers, and icons, improvement of the mental model and task specification, and improvement of the quality of the physical environment. These improvements focus on the needs of the user and help to create a product that is usable, adequate, and marketable.

29.3 METHODS OF ERGONOMICS AND DESIGN

This study combines the use of two methods: a typical method used in ergonomics, "macroergonomic work analysis" by Fogliatto and Guimarães (1999) and a typical method used in design, the "product design method" by Baxter (2000).

29.3.1 Macroergonomic Work Analysis

The macroergonomic work analysis (MWA) by Fogliatto and Guimarães (1999) is composed of the following phases:

- Phase 0: *Launching of the project* involves explaining the project objective, the phases, and the techniques to be used.
- Phase 1: *Ergonomic evaluation* involves investigating and mapping the "items of ergonomic demand" (IED). This phase includes the survey of users and field observations of the tasks using a questionnaire. It aims to identify ergonomic constraints and the user level of satisfaction.
- Phase 2: *Ergonomic analysis and diagnosis* refers to the identification, analysis, and ranking of the problems in the product use.
- Phase 3: *Ergonomic design* involves proposals for modifications of an existing product or new conceptual design generation.
- Phase 4: *Detailing and validation* involves the application of techniques to validate models and prototypes and the implementation of the modifications. It includes the detailing and testing of the proposals for requirement needs.

MWA is a participative ergonomics method and the macroergonomic approach is the core of this method in which user participation in the identification of ergonomic constraints and in the phases of conception and implementation of the proposed designs is justified because it guarantees greater involvement and inclusiveness and therefore a greater chance of success for the design (Brown 1995). A macroergonomic approach focuses on the human, the organization, the environment, and the machine as a more ample system, not restricting itself to questions relating to the workplace (Hendrick and Keiner 2002). As previously mentioned, MWA was originally designed to evaluate workplaces. However, in this study the method will be applied to study product use.

29.3.2 Product Design Method

The product design method by Baxter (2000) is used to understand the needs of the users in order to identify, specify, and justify the opportunity for the product design. This method emphasizes the issues related to the marketing of the product. Therefore, it involves the identification of a business opportunity, marketing research, bench marketing analysis, proposals, and specification for the new product. An innovative approach is required in order to create a new product identity and an aesthetic appearance to make the product more competitive in the marketplace.

This method comprises two phases: conceptual and configurational.

- The *conceptual phase* requires a lot of creativity by designers to solve the design problems that consider the user requirements. In addition, in this phase the problems and user needs are identified.
- The *configurational phase* involves the design and specification of each product components to be manufactured and the identification of the manufacturing process.

Depending on the design objective, a number of techniques may be used, such as brainstorming, brainwriting, analysis of similar products, and synchronic analysis. Table 29.1 shows a flow chart of the activities undertaken and the techniques used in the six stages of the activity management scheme proposed by Baxter (2000).

29.4 CASE STUDY: SYSTEM FOR PATIENT COMPANION RESTING/WAITING

29.4.1 Initial Considerations

The target system of the case study was the recovery room of a surgical clinic in a ward at the local university hospital in the city of Sao Luis, northeast of Brazil. The collection and analysis of data occurred in the recovery room during both day and night shifts. The ward in question is divided into three sub-sections: Block A (with 47 beds dealing with thoracic procedures, ENT, urology, proctology, cardiovascular, and general surgery), Block B (with 188 beds dealing with plastic surgery, thoracic, cardiovascular, and general surgery), and Block C (with 28 beds dealing with neurological cases, orthopedics, and Kit Central, an area responsible for the distribution of material to all the other areas). The Kit Center helps nurses (resident staff nurse, assistant nurses, and trainee nurses) working in all other areas of the hospital. During the day shift, there were 14 nurses, 19 assistant nurses, and 25 nursing trainees distributed throughout the three blocks.

It is important to point out that the research project was approved by the Research Ethics Committee of the University Hospital/Sao Luis—Maranhao State, Brazil, and followed the "Norm ERG BR 1002—Ethics Code of Certified Ergonomists by the Brazilian Ergonomics Association" (ABERGO 2003).

29.4.2 Macroergonomic Work Analysis Method Applied to the Design of a System for Patient Companion Resting/Waiting

In the first part of the study, macroergonomic work analysis by Fogliatto and Guimarães (1999) was used, involving the phases: launching of the project, ergonomic evaluation, ergonomic analysis and diagnosis, and ergonomic design with the aim to identify the ergonomic demands.

TABLE 29.1
Phases of the Baxter's Design Method with Stages and Techniques Used

Stages	Sub-stages	Techniques
Business opportunity	Problem analysis	Interviews
		Questionnaires
		Field observations
	Data investigation	Research analysis of similar
Project specification	Project requisites	Design briefs
Conceptual project	Generation of ideas	Brainwriting (Baxter 2000)
	Pre-project	Voting (Baxter 2000)
Configuration project	Breakdown	Structuring requisites (Bonsiepe 1984)
	Dimension testing	Questionnaires
		Contact area
Revisions (feedbacks)	Breakdown of project requisites	
	Project requisites (revision)	Brainwriting (Baxter 2000)
		Voting (Baxter 2000)
	Project concept (revision)	
	Concept test	Interviews
		Questionnaires
	Revision of project breakdown	Structuring requisites (Bonsiepe 1984)
Manufacturing project	Specification of materials	

29.4.2.1 Launching the Project

In this phase of the MWA method, details about the phases of this method were explained to nurses involved in the project.

29.4.2.2 Ergonomic Evaluation

This phase involves field observations. Data were collected using recorded images of the nurses' work in their workplaces. The recording collected images of each task performed at each sub-section. Information was also collected through informal interviews with the hospital management, safety engineers, and technicians. Nurses' opinion about their work was collected based on interviews and questionnaires. First, 31 nurses were interviewed, totaling 31% of the total of nurses working in the hospital. Interviews had a pre-established script, with open-ended questions like: "What is the worst part of your work?" The interviews took place during the shift work or between shift changes with the shift supervisors organizing the groups. Data from each sub-section were put together to build a standardized questionnaire so that the results of both sub-sections could be compared. Second, a questionnaire was prepared based on the results of the interviews and applied to 49 nurses with ages varying from 30 to 49. The aim of these questionnaires was to measure the nurses' satisfaction and perception regarding their work in all sub-sections that comprised the study.

In general, the ergonomic constraints found in the questionnaire were related to organizational, physical, environmental and biomechanical issues, and the workstations. The results of the questionnaire reveal two major sources of complaint: ergonomic and biomechanical constraints. The ergonomic constraints most highlighted were of an organizational order; such as low quantity of courses and training, high-level risk of accidents, low motivation due to low income, non-existence of a room exclusively used for first aid, working during weekends, lack of break times, reduced eating time, bad quality of drinking water, lack of drinking fountains, etc. The biomechanical constraints most cited were the high physical effort of transporting patients, bad working posture, long time spent on feet during work, excessive walking, etc. It is important to note that one of the mentioned ergonomic constraints indicated was the "lack of comfort for patients and their companions." This pointed out the need for a deeper investigation of hospital stays for patients and companions in order to help them during their stay at the hospital.

Among the ergonomic evaluation results, one caught the attention. The nurses agreed that the resting furniture for patient companions was totally inadequate or non-existent. Generally, there were no resting facilities available to people staying with patients, therefore, the companions used improvisation, usually with plastic chairs (injected polyethylene), sheets on the floors, and mattresses or sofas in reception areas (Figure 29.1).

Considering the design requirements and needs, the product design method proposed by Baxter (2000) was used. It involves the following phases: the generation of the concept of the product, the generation of a preliminary configuration, a usability test for the model in a real situation, and the design for the preliminary manufacturing of the product.

29.4.3 Product Design Method Applied to the Design of a System for Patient Resting/Waiting

Based on the results of the previous phase of the study (ergonomic evaluation), it was decided to perform the ergonomic design focusing on the companion's needs while resting/waiting at the hospital. The product design method (Baxter 2000) comprising the conceptual and configurational phases was used. In the first phase (conceptual), the principals were created (project requisites) for the development of the project using techniques such as open interviews and questionnaires. In the second phase (configuration), design proposals, performed tests, and revisions were generated.

FIGURE 29.1 Methods used by those trying to rest in a public hospital in the northeast of Brazil.

29.4.3.1 Conceptual Stage: Business Opportunity and Project Specification

Several steps were carried out:

A. *Open interviews and questionnaires*. Open interviews were conducted with 17 companions of hospital patients and 38 workers in the hospital, including nurses, nurse's aides, nursing technicians, technicians, operators, and social workers. The interview contained the following exploratory questions: "What do you think of the rest/wait system offered by this hospital?" "Who accompanies patients?" The participants' answers were collected in a field research notebook and served to create the questionnaire to collect the user profile information and measure the user satisfaction and perception regarding the rest facilities. The questionnaires were given to 180 patient companions and 20 staff. The results of these questionnaires will be discussed later in this chapter.
B. *Field observation*. A field observation was carried out on the hospital ward with the aim to understand how the patient companion rest/wait and which furniture/object they use. The observations were recorded by video and photography during the day and night shift work.
C. *Researching similar products*. Next, 20 products available in the marketplace used by the patient to rest were researched. Each one was analyzed and the best solutions available that could serve as a source of inspiration to the product design were identified.

D. *Design briefs*. Research on important points with a view to gaining knowledge of the most varied brands and models of similar products and to verify the solutions found by other project creators was done, including looking into websites of shops and specialized companies; these findings were submitted to a synchronic analysis using Bonsiepe (1984). The results of this research allowed the elaboration of the specifications of the design (design requirements) responsible for the presentation of the design goals. These goals needed to meet the product requirements and priorities and must guide the design process. The design requirements can be understood as a design concept that has as its objective to provide design principles for the new product in order to satisfy the consumer demands (patient companion demands) and differentiate the new product from others already in the marketplace. The design requirements were first classified as: requirements of use, how the product works—structural, technical-productive, economic, and formal. A second organization classified the requirements in order of priority, such as obligatory and desirable, as recommended by Bonsiepe (1984).

E. *Conceptual design ideas*: The phase of conceptual design is responsible for generating new ideas and product design concepts (Baxter 2000; Jones 1992). In this phase, some product design concepts using the technique "brainstorming" were generated. After the generation of ideas using the conventional brainstorming session, another technique known as "brainwriting" (Baxter 2000; Jones 1992) was used in order to improve the forms and proportions of the generated concept. As for the selection of the best alternative, the technique of "voting" was used (Baxter 2000) with a jury made up of ten people, among whom were five students from the design course, two designers, and three lay people.

29.4.3.2 Design Configuration, Revisions (Feedback), and Manufacturing Project

This phase included: (a) testing the dimensions and (b) detailing preliminary specification of the material, components, and structural elements, and the finishing of the product.

For the testing of product dimension a 1:1 ration model was built using plastic film and modeling clay (Figure 29.2). This model did not consider aesthetic issues or the ideal manufacturing materials. Interviews and a technique called "contact area" were carried out with a sample of users.

For the contact area test, four users were selected: a 95th percentile male (height: 1 m 87.5 cm) and a 5th percentile female (height: 1 m 51.6 cm), all between 21 and 34 years old. For this test, a model was made using plastic film and modeling clay (Figure 29.3).

While the chair was in the normal seated position the contact area left by the user was verified when they rose from the chair and left their impression in the clay, which was then photographed for further use.

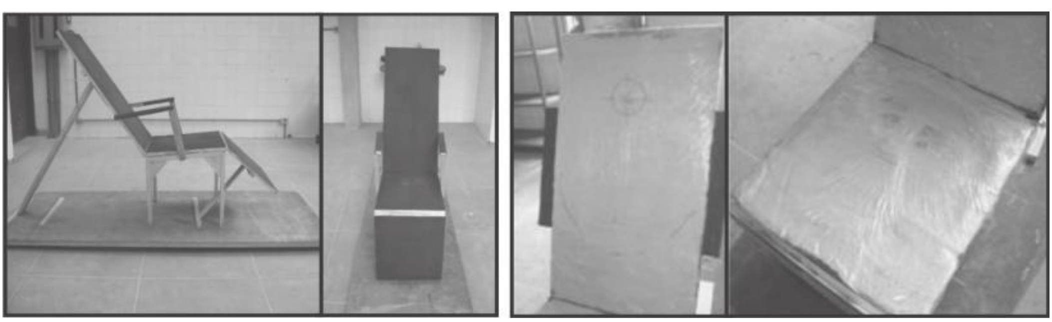


FIGURE 29.2 Model for dimension testing.

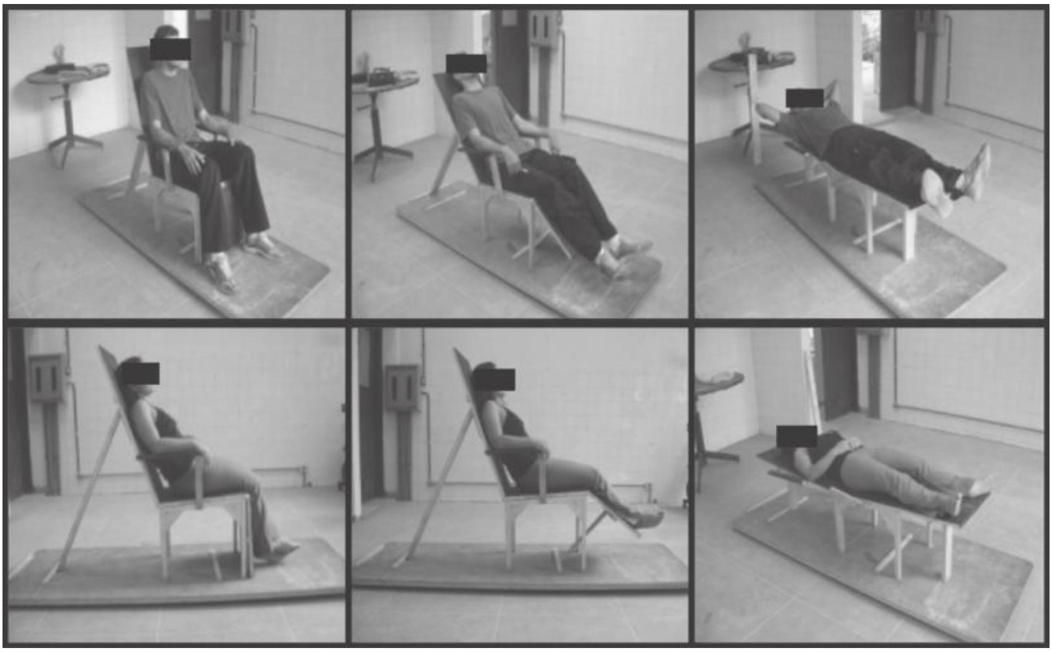


FIGURE 29.3 Users during the dimension testing.

A sample of 20 users were asked to attend an interview for which users from different dimensions were selected; five male users of the 95th percentile, five male users of the 5th percentile, five female users of the 95th percentile, and five female users of the 95th percentile. Each user evaluated the dimensions in different positions of the model and then answered questions in the form of an open interview and questionnaire. Figure 29.3 shows the different positions of the model.

The results of these analyses generated a need to revise the concept of the product in order to try to attain the product requirements that were not reached in the testing. After that, new solutions were proposed.

Another model including the revised product requirements was built. This was a functional model incorporating the structure of a poolside recliner available in the market, made of steel tubes, held together with a PVC covering, and upholstered with foam and a layer of synthetic leather 1 cm thick (Figure 29.4).

Usability tests were conducted with this model in order to verify the adequacy of the changes in a real context of use. This also allowed us to verify if the proposal in question is capable of positively corresponding to the requisites and to record the user comments about the safety, comfort, practicality, and versatility of the model.

The place chosen for the usability test was the neuro-orthopedic ward in the hospital where the research was carried out. According to the age group recommended by Guimarães (2004), based on Panero and Zelnik (2002), 12 people were selected (3 female users of the 5th percentile, 3 female users of the 95th percentile, 3 male users of the 5th percentile, and 3 male users of the 95th percentile). On the ward were chosen to participate in the test. This number corresponds to the intention to interview the extreme users according to the age group found in this research. The requisites of participant's height and age were approximated. These selected users represent the smallest and the tallest people who may use the resting/waiting system. To do this test, the user answered a questionnaire stating his or her opinion regarding the importance attributed by the user to the chair for patient companions. A chair was given to the users and an explanation

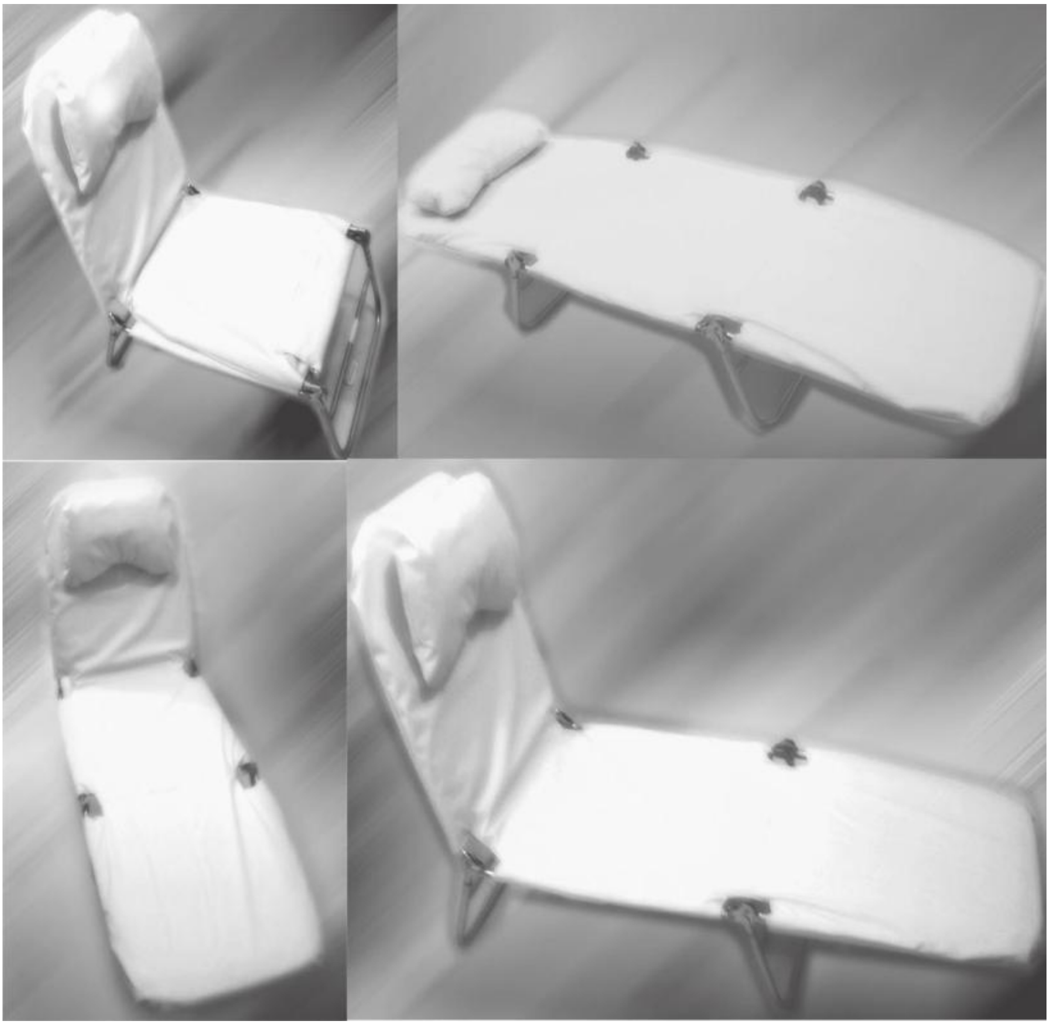


FIGURE 29.4 New more realistic concept model.

was given on how to assemble and disassemble it, how to alter the chair positions, and its possible positions for use. Then the user was required to mark a Linkett scale of the level of importance of items such as appearance (aesthetic) of the chair, safety, comfort, and suitability for rest. (The results are shown later in this chapter.) The user responded to a questionnaire that, in this second stage, included questions about the degree of importance of the subjects previously considered previously considered relating to the chair already tested.

Another test was carried out in order to observe the use of the chair for longer periods, e.g., while sleeping. The same sample of users was asked to perform this test and was video recorded while systematic observations were made for a period of three hours without interruptions. The video helped to identify how the users use the product. After that, the user was required to answer a second part of the questionnaire with questions about his/her perception of comfort regarding the seat, backseat, head and foot support during use.

A revision of the design concept was made after the tests with the realistic concept model and needs were identified for a new product, detailing and defining material specifications, structural components, forms, fittings, etc.

29.4.4 Results and Discussion

29.4.4.1 Results and Discussion of the Conceptual Stage

A system for patient companions should provide comfort and safety while improving their quality of life while waiting for the patient during their hospital stay. The results of the conceptual stage are stated below.

A. Open interviews and questionnaires

Interviews

The open interviews results show an elevated level of dissatisfaction regarding systems for resting/waiting available at the hospital. The users were mostly female, between 26 and 35 years old, comes from the interior of the state, height between 1 m 51 cm and 1 m 70 cm and weight between 56 and 70 kg. This details were collected via participant deposition, probably staying in the hospital for periods ranging from 1 to 14 days and may be staying full time.

Questionnaire

The respondents complained of back, leg, and neck aches and pains caused by several body positions used while trying to rest/sleep during overnight stays. The questionnaire results show that 89% of patient companions and 66% of the hospital employees were not satisfied with the rest/wait system available. This sample included data three areas of complaints (a) the quality of the material used in the rest/wait system (88% patient companions and 67% hospital employees); (b) the inadequate size of the rest/wait system (75% patient companions and 58% hospital employees); and (c) the space available to use a chair as a rest/wait system in the ward (41% patient companions and 58% hospital employees). When asked about suggestions, they were almost unanimous in that the rest/wait system should incorporate the function of a bed and a chair (86% patient companions and 75% hospital employees).

B. Field observation

During the systematic observation phase, it was observed that the most used system to rest/wait by the patient companions was a piece of paperboard or mattresses on the floor, plastic chairs, sofas, and patient beds not in use. This shows that because of a lack of concern on behalf of the hospital for the provision of an adequate way for the patient companions to rest/wait, these individuals were left on their own to improvise.

C. Researching similar products

A specific product used by patient companions to rest/wait was not found. Therefore, an attempt was made to identify a similar product that may have the same function. A beach chair was the product that most met the needs of the patient companions. This product has the adequate needed dimensions: low cost and easy to move/handle, clean, assemble and disassemble, and is also comfortable.

D. and E. Design briefs and conceptual design ideas

The product requirements found in the study were: easy maintenance, comfortable, easy to transport, use and store, safe, relatively small in size, adjustable, versatile (a chair-bed), stable, inexpensive, use of regional technology, be of semi-industrial manufacturing, cushioned with colors that avoid accumulation of dirt, and be finished with durable material adequate for the hospital environment. These items were included in the design brief.

From the design brief conceptual design ideas were generated using the technique of brainstorming (Figure 29.5).

After choosing the conceptual design alternatives, the forms and proportions of the generated concept were refined using the technique of brainwriting. This refined proposal included the design

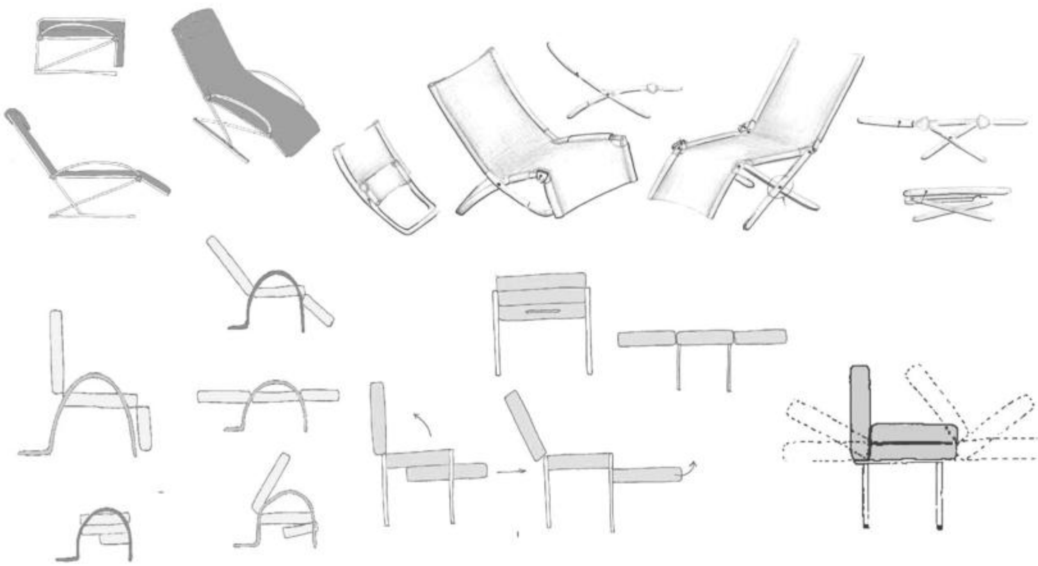


FIGURE 29.5 Sketches from the idea generation phase.

requirements and with it the final conceptual project called "chair-bed" was produced (Figure 29.6). The final product produced was a metal structure covered in synthetic material and foam. It permits the changing of body positions for sitting and lying and provides support for the legs and arms. Apart from being adjustable in four different positions, the chair-bed permits the user to sit, recline, and lie down, and it is easy to transport and store.

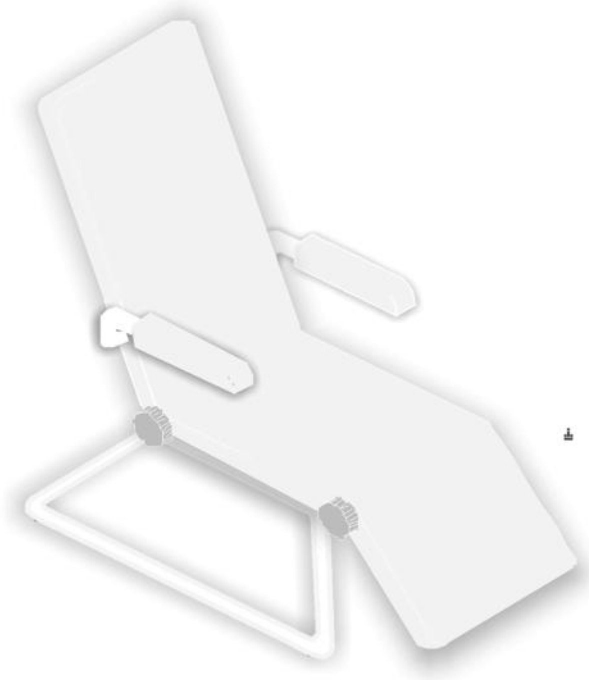


FIGURE 29.6 Final design proposal after refining the shapes and dimensions.

29.4.4.2 Results and Discussion of the Design Configuration, Revisions (Feedback), and Manufacturing Project

29.4.4.2.1 Test of Dimensions

The test of dimensions using the model shows: (a) adjustment in the reduction of the seat depth was required because the dimensions used in the model did not attend to the needs of the 5th percentiles male and female users ; (b) the absence of support for the head mainly while lying down and in the reclining positions was observed. This resulted in discomfort in the neck area requiring an adjustable pillow to be included as part of the product; (c) insufficient support for the legs in the lying down position caused discomfort for the 95th male percentile; (d) the width of the seat and backrest was inadequate for the 95th male percentile; Figure 29.7 shows the new product dimension after being changed by the anthropometric analysis.

29.4.4.2.2 Detailing

In order to prepare the design detail, a verification of the project requisites was made using a model from the final design proposal. The requisites were classified into three levels: attained, not attained, and need test. The "need test" indicates that it still needs validation by the user (Table 29.2).

While observing the table, it can be seen that two essential requisites of the product (ease of transport and storage) were not fulfilled in the model containing the final design proposal. Therefore, there was a need to generate new ideas and concepts that should satisfy these specific requisites while maintaining those already included.

29.4.4.2.3 Revision of the Refined Design Concept

This phase was carried out in order to generate design ideas for the development of new solutions to solve the problems of transporting and storing the item. From the concept of a reclining beach chair, associated with the concept of hospital armchairs already existing in the marketplace, a conceptual

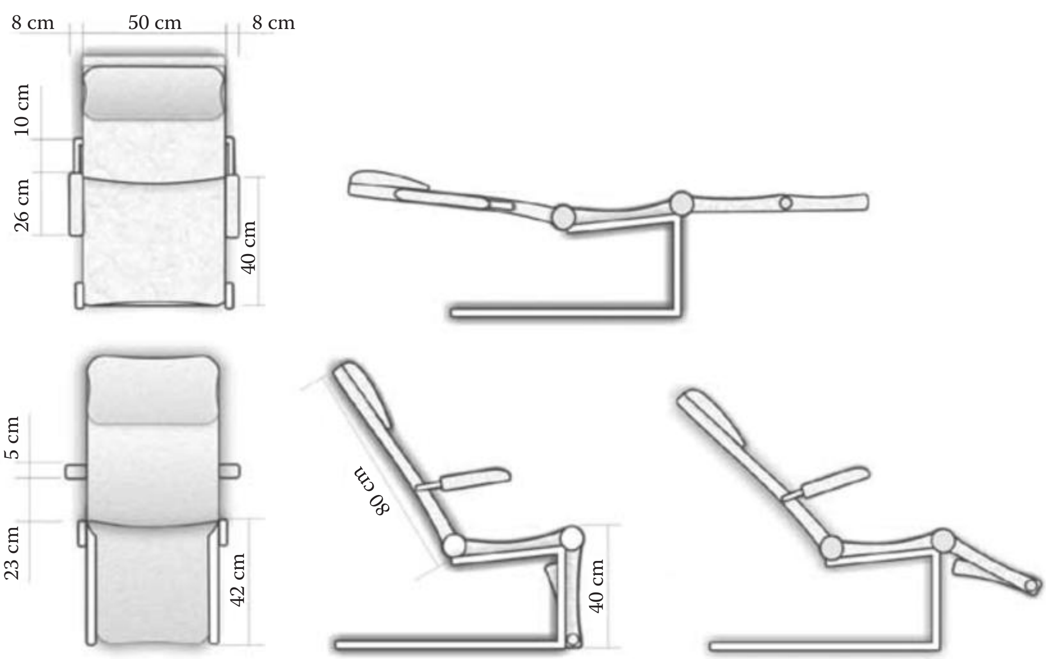


FIGURE 29.7 Proposed product dimensions.

TABLE 29.2
Verification of the Projects Requisites

Requisites	Level
Ease of maintenance	Attained
Comfortable	Test
Adjustable positions	Attained
Support for arms	Attained
Support for the head	Attained
Support for legs and feet	Attained
Ease of transport	No
Ease to storage	No
Safe	Attained
Reducible dimensions	Attained
Adjustable	Attained
Easy to operate	Test
Versatility (chair-bed)	Attained
Resistant	Attained
Structure and material adequate for a hospital	Attained
Metal structure	Attained
Finished in synthetic material and foam	Attained
Stable	Test
Local technology	Attained
Semi-industrial manufacturing	Attained
Low cost of production	Attained
Cushioned	Attained
Colors that retain clean appearance	Attained

proposal of a new design solution was found. This new solution solved the identified problems of transport and storage using a light, folding, and compact structure (Figure 29.8).

29.4.4.2.4 Testing the Refined Design Concept

The 12 selected users were invited to test the refined design concept in a test of usability (Figure 29.9). The results showed that for the majority of the people taking part in the testing, the

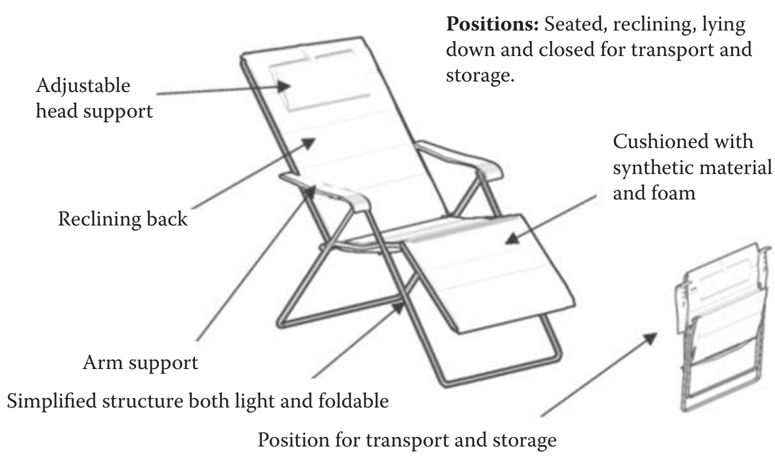


FIGURE 29.8 Conceptual proposal.

FIGURE 29.9 Seated position of the product and mounted/upright position.

chair corresponded to their expectations in terms of practicality, versatility, and safety. Opinions differed more on the questions of appearance and comfort. All the users claimed to be dissatisfied with the height of the chair. This result implied the need to verify alternatives that would enable adequate posture in the seated position and in the reclining position of the chair-bed.

Another relevant factor cited was the covering of the sub-system of adjustment of positions, which exposed diverse parts that might possibly injure the user during use. Some of the users, especially the older ones, had problems setting the chair up because there is a need to stretch the upper body while manipulating the product. These users took on average 42 seconds to set the chair up while the average time for the other users was only 23 seconds. It was also noted that the legs of the chair frequently slipped, indicating the need to create an alternative to increase the grip that the chair had on the floor to avoid this slippage. Another observation was related to the lowness of the seat, meaning that the user needed more help in sitting up or actually getting up from the chair. The absence of arms on the structural model made sitting in and getting out of the chair difficult (Figure 29.10).

It was observed that while reclining in the chair there was a need to constantly manipulate the legs of the chair to keep them in contact with the floor. This could be prejudicial since this contact may improve the possibility of contagiousness by some pathogenic microorganism present in the hospital.

The refined design concept test of the model in a real situation showed satisfactory results in terms of the development of ideas for the new product. The proposal was well accepted by the users, the majority of whom considered the chair-bed comfortable and adequate for resting. Some project items still needed further work; such as the height of the seat, arm support, and the addition of some element which helps the legs of the chair to have better grip on the floor in order to avoid user's contact with hospital germs and bacteria.

The recommendations from the refined design concept test generated another design proposal incorporating all user suggestions (Figure 29.11), the specifications for the manufacturing processes (Table 29.3), and materials and components (Table 29.4).

FIGURE 29.10 Sitting and getting up from the chair.

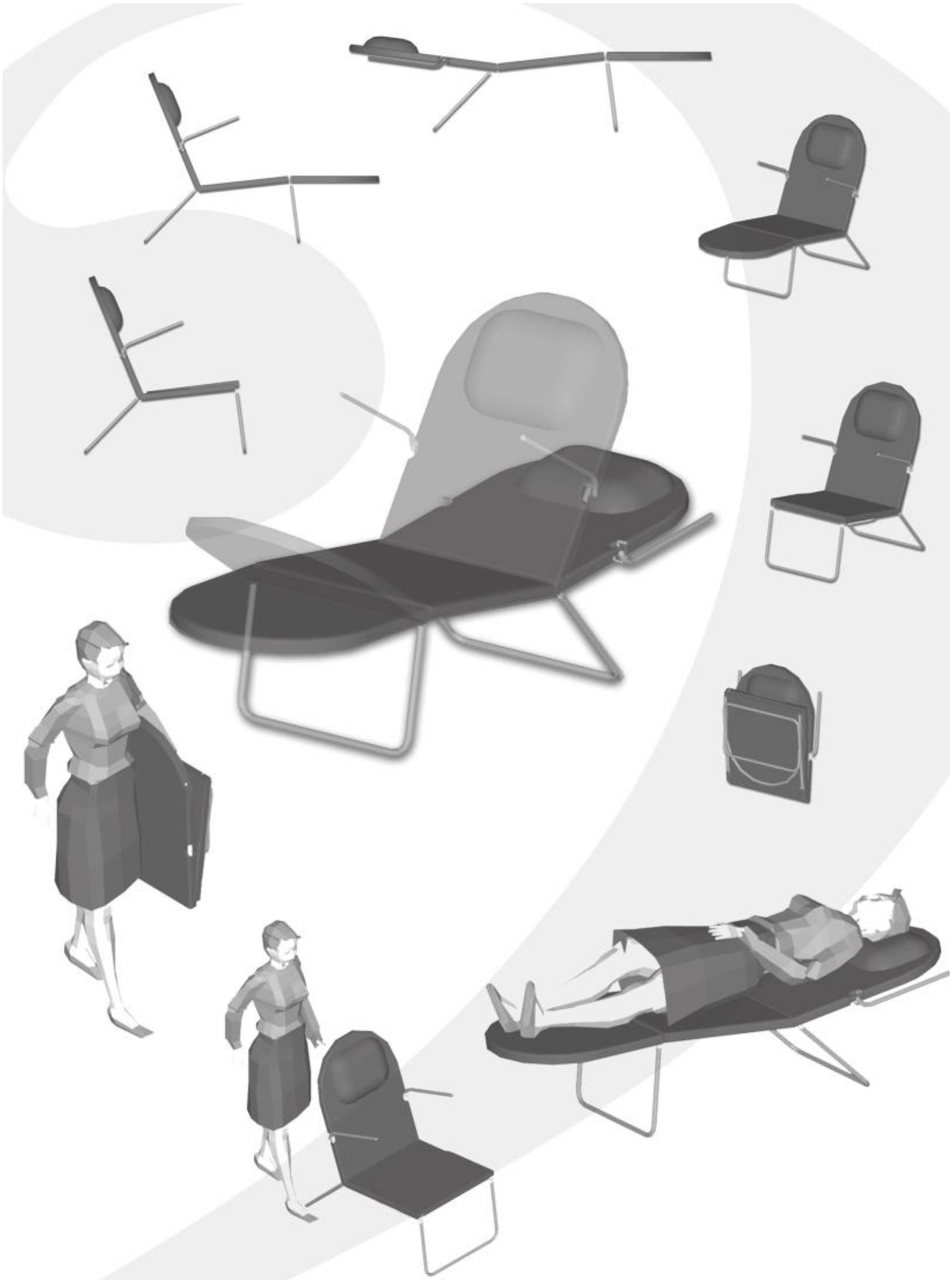


FIGURE 29.11 *Rendering* of the "chair-bed."

TABLE 29.3
Specification of the Manufacturing Processes

Specification	Process
Internal and visible structure. Arm support	Cuts, perforation, and folding of aluminum tubing. Joints: riveting and soldering
Internal structure of cushion support	Cut of lining. Joint: seams
Cushioning	Cuts of foam and synthetic leather. Joints: seams
Sub-system of position adjustment	Cuts, perforation, and folding of aluminum sheets. Joints: riveting

29.5 FINAL CONSIDERATIONS

The results showed that for this product to attain ease of mobility and ease of folding, it should have a simple structure. The proposal reproduced a structure similar to that of a reclining beach chair with the necessary changes made for the hospital environment in a way that guarantees comfort for its users.

In this way, the innovative proposal, which modified the principals of the reclining chair, was used to generate new design concepts. The usability tests made in a real situation at the neuro-orthopedic ward of the university hospital in Sao Luis city in Brazil, show that the results were satisfactory in terms of the development of the design concept.

It ought to be taken into consideration that a specific product for use by patient companions to rest/wait was not identified in the market place. In addition, the problem of lack of space in the ward to include such a product represents a challenge to designers. Designing a new product to fulfill a need means the responsibility to insert one more element in the existing reduced space. It is necessary to consider that the new product will not create an obstacle to the main objective of the tasks carried out in the ward by the nurse, i.e., caring for sick patients.

The design to create a product to fulfill the needs of the companion accompanying a patient for rest/waiting will not solve the identified problems. There will be a need of a layout study which allows space for the development of all activities involved in the context: patient, nurses, patient companions, and the medical team.

Regarding the use of two distinct methods converging in one design method, the study shows that it had some advantages such as the easiness to elaborate the design brief. The use of the phases of ergonomic appreciation and ergonomic diagnostics applied at the start of the project helped to

TABLE 29.4
Specifications of Materials

Item	Specification	Description of Material
01	Internal and apparent structure. Arm support	Aluminum tubing 7/8" (22.22 mm) with wall 0.278 (1.58 mm)
02	Sliders for the “legs”	Rounded slider
03	Arm support	Aluminum tubing 7/8" (22.22 mm) with wall 0.278 (1.58 mm)
04	Sustaining structure	Cotton lining
05	Rivets	Solid aluminum rivets 1/4 × 9/16"
06	Cushioning	Laminated foam D28 2 cm
07	Covering	Synthetic leather
08	Sub-system of positional adjustment	Aluminum sheets
09	Sub-system of springs for positional adjustment	Helicoid spring with six twisting spirals

identify the design problems to be solved. On the other hand, the excessive feedbacks to the design configuration, as a consequence of the usability tests, requires a long time in the whole design process.

ACKNOWLEDGMENTS

The authors are grateful to Gabriela Ribeiro, Livia Flávia Campos, Eliane Nascimento, Ellayne Paiva, and all the students of design, Federal University of Maranhão, Brazil.

REFERENCES

Abeni, K. 1988. An assessment of industrial designers use of human factors criteria in product design evaluation. In *Proceedings of the Human Factors Society – 32nd Annual Meeting*, 420–24. Santa Monica, CA: Human Factors Society.

ABERGO. 2003. *Norm ERG BR 1002. Ethics Code of Certified Brazilian Ergonomists*. ABERGO, Brazilian Ergonomics Association. Rio de Janeiro (in Portuguese). abergo.org.br: http://www.abergo.org.br (accessed June 17, 2010).

Baxter, M. 2000. *Product Design: Practical Methods for Systematic Development of New Products*. São Paulo: Edgard Blücher (Portuguese Edition).

Blaich, R. 1987. Ergodesign as a corporate strategy. *Behaviour and Information Technology* 6 (3): 219–27.

Bonsiepe, G. 1984. *Experimental Methodology: Product Design* [in Portuguese]. Brasilia: CNPq/Editorial Coordination.

Brown, O. Jr. 1995. The development and domain of participatory ergonomics. In *Proceedings of the IEA World Conference, 3rd Latin American Congress, 7th Brazilian Ergonomics Congress*, eds. A. de Moraes, and S. Marino, 28–31. Rio de Janeiro: Brazilian Ergonomics Association.

Brown, G.N., and Wier, A.P. 1982. Human factors and industrial design (are we really working together?). In *Proceedings of the Third National Symposium on Human Factors and Industrial Design in Consumer Products*, 3–10. Santa Monica, CA: Human Factors Society.

Chapanis, A. 1994. Ergonomics in product development: A personalized review. In: *Proceedings of the IEA Congress*, eds. M.L. Innes and M. Hill, Vol. 1, 52–54. Toronto, Canada: Human Factors Association of Canada.

Cushman, W.H., and Rosenberg, D.J. 1991. *Human Factors in Product Design*. Amsterdam: Elsevier.

Daniellou, F. 2007. The ergonomics of project conduct for work systems concepts. In *Ergonomia* [in Portuguese], ed. P. Falzon, 303–15. Sao Paulo: Editora Blücher.

Darses, F., and Wolff, M. 2006. How do the designers represent to themselves the users' needs? *Applied Ergonomics* 37:757–64.

Fogliatto, F., and Guimaraes, L.B.M. 1999. Macroergonomic design: Method proposed to product design. [In Portuguese.] *Produto & Produção* 3 (3): 1–15.

Grandjean, E. 1984. Foreword. *Behaviour and Information Technology* 3:261.

Guimaraes, L.B.M. 2004. *Product Ergonomics* [in Portuguese]. 4th ed. Vol. 1. Porto Alegre: UFRGS/PPGEP.

Harris, C.M.-T. 1990. A study in the marketing of ergonomic expertise in the industrial setting. *Ergonomics* 33:547–52.

Hendrick, H., and Keiner, B. 2002. *Macroergonomics: Theory, Methods, and Applications*. Boca Raton: CRC Press.

Jones, J.C. 1992. *Design Methods*. New York: Wiley.

Karwowski, W. 2005. Ergonomics and human factors: The paradigms for science, engineering, design, technology, and management of human-compatible systems. *Ergonomics* 48 (5): 436–63.

Kreifeldt, J. 1984. Human factors considerations in consumer product design: A design integrate review. In *Proceedings of the 1984 International Conference on Occupational Ergonomics*, eds. M.L. Matthews and R.D.G. Webb, Vol. 2, 115–27. Toronto, Ontario.

Kreifeldt, J.G., and Hill, P.H. 1976. The integration of human factors and industrial design for consumer products. In *Proceedings of 6th Congress of the International Ergonomics Association*, 108–12. 20th Annual Meeting of Human Factors Society. Santa Monica, CA: Human Factors Society.

Lingaard, G. 1989. Defining what helps: An iterative approach the systems design. In *Proceeding of the 25th Annual Conference of the Ergonomics Society of Australia. Worldwide Information Systems – Bull.* Australian Construction Services (Department of Administrative Services), eds. J. Frith, B. Green, T. Levick, and M. Regan. Canberra, Australia: Ergonomics Society of Australia.

Lobach, B. 2000. *Design industrial: bases para a configuração dos produtos industriais*. São Paulo: Edgard Blücher.

Meyer, P. 1989. Extending the boundaries: Ideas for ergonomic products. In *Proceeding of the 25th Annual Conference of the Ergonomics Society of Australia. Worldwide Information Systems – Bull.* Australian Construction Services (Department of Administrative Services), eds. J. Frith, B. Green, T. Levick, M. Regan, 343–49. Canberra, Australia: Ergonomics Society of Australia.

Moraes, A. 1992. Ergonomic diagnosis of the communication process of a man-machine system; work station information terminals for data entry. Doctoral thesis. School of Communication, Federal University of Rio de Janeiro. (In Portuguese.)

Panero, J., and Zelnik, M. 2002. *Human Dimension in Interior Space* [in Portuguese]. Barcelona: Gustavo Gili.

Pheasant, S. 2005. *Bodyspace: Anthropometry, Ergonomics and the Design of Work*. 3rd ed. London: Taylor & Francis.

Ryan, J.P. 1987. Consumer behaviour considerations in product design. In *Proceedings of the Human Factors Society – 31st Annual Meeting*, 1236–39. Santa Monica, CA: Human Factors Society.

Smith, I. 1987. The case of the missing human factors data. In *Proceedings of the Human Factors Society – 31st Annual Meeting*, 1042–43. Santa Monica, CA: Human Factors Society.

Soares, M.M. 1999. Translating user needs into product design for disabled people: A study of wheelchairs. PhD thesis. Loughborough University, UK.

Stanton, N.A., and Young, M.S. 1999. Ergonomics methods in the design of consumer products. In *Occupational Ergonomics Handbook*, eds. W. Karwowski and W. Marras. London: CRC Press.

Ward, S. 1990. The designer as ergonomist. Ergonomics Design of Products for the Consumer. In *Proceedings of the 26th Annual Conference of the Ergonomics Society of Australia*, eds. B. Embling, M. Dispain, M. Goode, K. Newman, R. Barton, and V. Demczuk, 101–106. Adelaide, Australia: Ergonomics Society of Australia.

———. 1992. Product design and ergonomics. *Ergonomics Australia* 6:15–18.

Wood, D. 1990. Ergonomists in the design process. Contemporary products shed new light on avenues for interaction between ergonomists and industrial designers. Ergonomics Design: Products for the Consumer. In *Proceedings of the 26th Annual Conference of the Ergonomics Society of Australia*, eds. B. Embling, M. Dispain, M. Goode, K. Newman, R. Barton, and V. Demczuk, 125–132. Adelaide, Australia: Ergonomics Society of Australia.

Ergonomics and Human Factors

Human Factors and Ergonomics in Consumer Product Design
Methods and Techniques

Every day we interact with thousands of consumer products. We not only expect them to perform their functions safely, reliably, and efficiently, but also to do it so seamlessly that we don't even think about it. However, with the many factors involved in consumer product design, from the application of human factors and ergonomics principles to reducing risks of malfunction and the total life cycle cost, the process just seems to get more complex. Edited by well-known and well-respected experts, the two volumes of *Handbook of Human Factors and Ergonomics in Consumer Product Design* simplify this process.

The first volume, **Human Factors and Ergonomics in Consumer Product Design: Methods and Techniques**, outlines how to incorporate Human Factors and Ergonomics (HF/E) principles and knowledge into the design of consumer products in a variety of applications. It discusses the user-centered design process, starting with how mental workload affects everyday interactions with consumer products and what lessons may be applied to product design. The book then highlights the ever-increasing role of information technology, including digital imaging, video and other media, and virtual reality applications in consumer product design. It also explores user-centered aspects of consumer product development with discussions of user-centered vs. task-based approach, articulation and assessment of user requirements and needs, interaction with design models, and eco design.

Features

- Delineates how the Human Factors and Ergonomics body of knowledge can be used as a tool for designing consumer products
- Discusses the user-centered approach with definitions of users and the tasks they perform
- Explores how to translate design research into useful and usable products
- Covers human design technology, consumer products conceptual design, and development of smarter products using a systems engineering approach
- Focuses on creativity, innovation, standards and guidelines, culture, environment, affect, aging, and complexity in product design process

With contributions from a team of researchers from 21 countries, the book covers the current state-of-the-art methods and techniques of product ergonomics. It provides an increased knowledge of how to apply the HF/E principles that ultimately leads to better product design.

46284

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ISBN: 978-1-4200-4628-1
90000
9 781420 046281
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