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SPECIAL ISSUE ON HUMAN TECHNOLOGIES FOR SPECIAL NEEDS

José Juan Cañas, Guest Editor

Pertti Saariluoma, Editor-in-Chief

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From the Editor-in-Chief

THE IMPORTANCE OF THE FREE FLOW OF INFORMATION AND KNOWLEDGE

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Since the dawn of the Industrial Age, our societies have seen a continual, incremental flow of more and more complex technologies and new practices involving human-technology interaction. When looking at the development of these technologies, one begins to notice that the innovations are reflected first in the general knowledge that influences product design and production, which is then spread within the society by specialized companies. It is rare indeed when a new innovation, perhaps products such as cellular cameras or mobile TVs, takes the general audience by storm or is spontaneously produced in final form. For the most part, new ideas result in small changes: progress that the average person hardly notices. Perhaps the innovations reflect changes in the knowledge of ergonomics, or about the emotional impact of a design. Ultimately, much of what happens in improving human-machine interaction is completely unknown to the user.

This same reality can be found in the knowledge generation needed for conceiving and developing technical innovations. New or expanded knowledge can often be outside the gaze of designers and engineers. Sometimes this is because they have no need to be aware of the mathematics, physics, or material knowledge required, for instance, to create a quality lens for a camera phone. The usefulness embedded within a particular knowledge is often considered meaningless unless one is a specialist addressing particular problems. Those addressing other problems may easily underestimate the necessity of basic scientific knowledge derived from investigating human-device interaction.

For example, an underestimation of the psychological knowledge about human perception and behavior is especially easy because people regularly use their own intuitions and behavioral experience as the grounds to resolve interaction problems. While there are times when this might be effective, more often these intuitive approaches bring their own risks and create their own problems. One’s own intuition can be counter to established knowledge in interaction design, and solutions to perceived problems may violate the general principles of human information processing. Therefore, accurate knowledge about the true problem, about the complex aspects that affect the problem and potential solution, and about how humans tend to think, react, and behave is essential for developing practical, innovative

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solutions. It requires getting the requisite knowledge in applicable form to the best point in the design process. And many times, to reach this goal, we must break down some mental barriers that we have built inside our minds.

Throughout recent centuries, the world has witnessed groups of highly skilled individuals within specific arts and sciences who raise the level of quality as the result of social interaction. These groups can be called skill or technological subcultures. Examples of these subcultures include the artists of the Italian Renaissance, the composers and musicians in 18th and 19th century Vienna, or the Swiss watchmakers. Because of their close proximity to other members within this subculture, new ideas, new approaches, and creative thinking flowed freely among them, raising the level of quality for all—perhaps substantially beyond what any of these individuals might have accomplished if working alone. As a result, the artisans within the ranks of these subcultures became globally known for their expertise, even though they remained locally based. Today, such subcultures are spread across the globe. Therefore the need for knowledge to become more widely dispersed is essential. To get new information to the right people at the right time requires knowledge producers to break down many different barriers.

The barriers to the flow of information are not just geographic. A fissure can be found between universities and private companies, which tacitly means between scientific knowledge and product knowledge. With the pace at which technological innovations today surface and find their way into practical use in societies, it seems maintaining a division of labor between the two types of organization in regard to interaction design is counterproductive to both camps. Knowledge becomes significant only when it is expressed in practical terms, such as product development and other applications. However, information becomes knowledge and applicable only when built upon the ever-growing body of basic knowledge, which is discovered in the academic inquiry of the university.

To achieve such a complementary fusion of knowledge, those interested in the creation and application of knowledge need to find ways to scale the fences that might separate them. Such fences involve the languages (both cultural and terminological) of the fields of expertise, the different social rules and forms of expression between and within organizations, a lack of trust, and varying goals and interests, to name a few, which create barriers to effective communication and the quality use of knowledge. One possible means of bridging the gap between these distinct cultures is through open access scientific publishing.

Open access journals make knowledge and discovery freely available for those who need it. As search technologies gradually improve, knowledge seekers shall undoubtedly find it much easier to surface the pieces of knowledge needed from among a great variety of available information. Open access journals allow those who seek information to find those whose prior seeking has resulted in new perspectives, new data, new knowledge. For this reason alone open access journals are an essential part of communicating about scientific research findings and knowledge. And it seems that open access publishing is an especially natural way for university research to be distributed for the greater good. The salaries paid to university researchers normally come from public money, by extension from the taxpayers. Ethically, it seems a good principle that knowledge generated through the support of the general public should be equally available and, perhaps beneficial, to all the members of society.

In years past, the university was viewed as a local school, where young students learned what they needed to know through oral instruction from those more highly trained. The students attended the lectures, fulfilled their requirements for study, perhaps completed some type of research project, and were awarded degrees as competent masters or doctors of their fields. When they left the university, they rarely needed to come back for more. But in today's ICT-infused world, this historical reality is no longer valid—and in fact cannot exist. No one is ever fully competent, because knowledge advances with increasing speed. Throughout the world, knowledge is being generated in incremental pieces; those envisioning innovation must seek out important pieces of knowledge everywhere and all the time.

One particularly important example of a field where this free and wide flow of information is needed is represented in this special issue. In developing innovations and products for all of us, including individuals or user groups with special needs (e.g., the physically, cognitively, affectively, or sensory challenged), product innovators must be able to discover—and be inspired by—the new knowledge generated through university research and company implementation. Open access publishing can play a vital role in disseminating both basic research knowledge and the results of applied experimentation.

If universities keep the new knowledge behind their walls or offer limited access to it, then they have overlooked their duties to society. And if government officials, who make decisions regarding university funding for research and dispersal of research knowledge, do not see that new scientific innovations must be easily and effectively offered for the use of society, then the barriers to innovative use of new ideas slow down the availability of knowledge to those who need it and who have paid through their taxes to create it.

The time seems right to give up the old images and practices regarding research, knowledge, and innovation. Open access publishing makes it possible, but also necessary, to look at the role of basic knowledge within society and the roles of university research in the webs of innovation management in a new way.

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Guest Editor's Introduction

TECHNOLOGY FOR SPECIAL NEEDS

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Human beings use technology to perform all types of tasks. An important issue related to this unquestionable fact is that technologies must be designed so that they can be used by all types of people without any discrimination of age, educational level, abilities, health conditions, and so forth. The term *accessibility* has been proposed to refer to the parameter that measures the degree to which technology use is not limited by any physical or cognitive barrier. Accessibility is an essential component of the *usability* parameter that refers to the ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component (International Organization for Standardization [ISO],1998).

Accessibility is an issue related to users that have some kind of physical or psychological characteristics that impose any number of barriers to technology use. For example, there are people such as paraplegics with some physical limitations for interacting with a personal computer. It is evident that the input systems of the interface designed for a paraplegic cannot be those that are found commonly in the devices of general use. Other obvious examples of users with special needs are those that have some sensorial deficits, like blindness or deafness.

People with mental disabilities also face many challenges in today's complex technological environment and in the pace in which life and technological advancements take place. These people can have difficulties, for example, reading signs when they are on the street, at the post office, or in a hospital. In order to help mentally disabled individuals avoid the problems in situations that can seem trivial to many people (such as finding the washbasin in a public place), technological aids are needed.

A special user group for which accessibility is an essential parameter is the elderly. The increasing number of elderly people in our societies and the changes in the social structures in caring for them that have occurred in recent decades causes us to recognize the necessity for designing a variety of technologies for attending to them in their daily activities (Czaja & Lee, 2003).

Diversity in Research Perspectives, Needs and Contexts

In this issue of *Human Technology*, we have collected six papers that cover some important aspects in the design of accessible technology. Vanderheiden (2003) defines accessible

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technology as being able to be used by people with special conditions either directly or with assisting components that would allow them to overcome their limiting conditions. According to this definition, there are two characteristics that accessible technology must have: (a) It cannot have a characteristic that limits its use by people who have some disability; in other words, present an inflexible barrier that limits its use by people with impaired movement or sensorial input; and (b) It should be designed with some special component so that a person with some special motor or cognitive limitation can use it. The research presented in these papers provides examples of both characteristics. One example of the first characteristic can be seen in the paper by Väyrynen, Röning, and Alakärppä. The authors conducted an extensive series of field and usability studies to understand users' needs before designing new technologies. The authors acknowledge a very important aspect of these studies: the identification of user limitations for using new technologies.

With respect to the second characteristic, the paper by Mauri, Granollers, Lorés, and García addresses the important design issue of providing specialized input devices for people with severe movement restrictions, like people with cerebral palsy. They proposed that computer vision-based interaction could be the solution for these users. Therefore, the authors present two possible devices, the Facial Mouse and the WebColor Detector, that show promising results after user evaluation. In the same line of thinking, Garay, Cearreta, López, and Fajardo address the design of devices for communicating emotions for those people who, due to some kind of disability, are *emotionally handicapped* (Gershenfeld, 2000). They designed a multimodal and multistage affective mediation system for people affected by mobility and speech impairments. The system, called *Gestele,* is a promising prototype that adds information related to the user's emotions. This is a step forward in reaching an effective way for affective mediation for those people who are challenged in expressing their own or in interpreting others' emotions.

Designing technology for people with special needs must be done while taking into consideration four basic facts:

(a) It must start by detecting the special needs of particular users. Not all handicapped people are the same, even when some people are classified within the same category. For example, two quadriplegics could have different movement impairments.

(b) Technology must solve user problems, but never create new problems. This means, for example, new technology that is too invasive, or that monitors the movements too closely, should be used only when strictly necessary.

(c) Technological systems must be simple, economically accessible, and easy to learn.

(d) The systems should fit into the user's environment, be fun to use, respectful of their privacy, and so forth.

The system for assisting senior citizens in their homes through the use of a small robot that was designed and described by Baillie and Schatz in their paper is a good example of how a device designed for helping the elderly should not affect the fixtures or fittings of their homes.

We could and should approach the design of technology for people with special needs from different perspectives and methodologies. Väyrynen et al. used a multidisciplinary approach in which elderly users of videotelephonic services are viewed as active partners in the design of sociotechnical systems from which they benefit. The authors used a user-centered, participatory usability methodology, called PERDA, in which users (including elderly users and the people that provide services to them), designers, and a wide group of professionals that included ergonomists, psychologists, anthropologists, and so on, analyzed together the technology in the different phases of the iteration process. The aim of this methodology was the discovery of users' needs, the characteristics of the technologies that could satisfy those needs, and the design errors that could limit their use by the elderly. The methodology included all methods and techniques used in the many different disciplines of the research team.

Ojel-Jarmillo and Cañas present a different approach. They took a particular usability problem, the calls that users of telecare devices make by error, and tried to find a design solution by analyzing the cognitive characteristics of elderly users in relation to the device's characteristics. Their analysis allowed them to propose a hypothesis that could be tested by an experiment. The results of their experiment showed that changing a specific design characteristic can reduce the number of erroneous calls made.

The number of contexts in which people with special needs live and for which technology could be designed to make their lives easier is enormous. This fact simply means that this field is broader and deeper than many might think. However, an important technological environment in which accessibility must be taken into account is education. Nowadays, computer-based learning is being integrated into educational systems all over the world. Therefore, technology designed for providing learning environments must consider that learners could have a wide range of health conditions and disabilities. In addition, technology is now a key learning tool used specifically for individuals with cognitive and/or physical disabilities. This reality was addressed by Maguire, Elton, Osman, and Nicolle in their paper. They described an IT-based Virtual Learning Environment that supports learners with severe cognitive and physical disabilities. The design of this environment is a very good example of how accessibility in today's technology can lead to creative solutions for various needs. For example, tutors using this system could modify input device settings to suit different students' needs. There could not be any better example of the meaning of accessibility.

The Benefits of Technology for All in Modern Living

These six papers represent only some of the aspects of the multifaceted issue of access to technology by people challenged by mainstream interfaces, although they are some important ones. However, we must note that the topics addressed in the papers point to the fact that this field is open to many new technological developments, as well as that these issues regarding, questions about, and possibilities for making the technological benefits available for the diversity of people and needs should be the first item on the research agendas of designers, ergonomists, human factors specialists, and other professionals involved in designing human technology. All of these topics revolve around a central idea: Disabled people need technology to perform their daily activities by themselves just as nondisabled people do. For example, people with psychological or physical disabilities have social lives in which they participate in social and interpersonal encounters, just as other people do.

In a quality program of care for disabled people, the days include meetings and training sessions. In addition, the special needs individuals often must be reminded of things, such as, for example, when to take their medicines. Since there is a shortage of caretakers, and the few people in these roles rarely have enough time to address every need of their clients, disabled people need to be able to remember or address needs by themselves. That is to say, they need to be able to take better control of their own time and knowledge about their activities. Many disabled people want to be able to live alone but they need technologies to assist in controlling potentially dangerous tools in the home, such as gas furnaces, electrical equipment, and open faucets. They also want to have the possibility of moving around and visiting the places that are of interest to them. These desires and needs of members of our societies provide ample reasons for designing devices to help them in carrying out all their daily activities.

In reading the papers that follow, I have a suggestion for the readers' consideration. It is becoming ever more clear that there can be a confluence of objectives between the designers of devices for disabled people and the designers of new devices for everyday situations. For example, Vanderheiden (1998) suggests that some aspects of accessibility to the Internet for disabled people are similar to those that must be considered in the design of mobile systems for accessing the Internet (e.g., PCs with Internet designed to be used in cars). Also, if we think about the design of technology that helps disabled people to live independently and visit places of interest, we could recognize that the important research effort for developing systems that locate geographical positions (as the GPS, or systems of global positioning, do) could be easily incorporated into technology for people with special needs.

This issue of *Human Technology* provides further encouragement for all designers, engineers, and others involved in technological development to see the mutual benefit of approaching accessibility and usability from a global perspective. Everyone in our societies benefits when universal design and the needs of the users serve as the foundation for creative new approaches to technology.

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USER-CENTERED DEVELOPMENT OF VIDEO TELEPHONY FOR SERVICING MAINLY OLDER USERS: REVIEW AND EVALUATION OF AN APPROACH APPLIED FOR 10 YEARS

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Abstract: *A research and development (R&D) approach has been applied to video telephony (VT) in northern Finland since 1994 by broad consortia. The focus has been on the considerable involvement of ergonomics within the engineering and implementation of VT. This multidisciplinary participatory ergonomic R&D approach (PERDA) is described briefly, in general and through two cases. The user-centeredness should be discernible in this sociotechnical systemic entity. A consortium—comprising mainly manufacturers, individual and organizational users of technological products, and R&D organizations—serves as a natural context for product development. VT has been considered to have much potential for enhancing (multimedia) interaction and effective multimodal communication, thereby facilitating many activities of everyday life and work. An assessment of the VT system, called HomeHelper, involved older citizens, as clients or customers, and the staff of social, health, and other services.*

Keywords: *ergonomics, older users (of technological products), participation, research and development, usability, user-centered design, video telephone.*

INTRODUCTION

A participatory ergonomic research and development (R&D) approach, PERDA, with an emphasis on user-centered technology and usability, has been applied to video telephony (VT) and its applications in northern Finland, and has been facilitated by consortia of research partners. The PERDA projects have been managed by the University of Oulu, usually

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in cooperation with the University of Lapland. A multidisciplinary academic research group, consisting of ergonomists, computer and software engineers, industrial designers, psychologists, physicians, nurses, and anthropologists, has been operating various R&D consortia together with a number of hardware, software, and service companies, as well as public sector partners. The principal idea of PERDA (Väyrynen, Tornberg & Kirvesoja, 1999) and the academic core of the PERDA consortia have remained the same for 10 years. The stakeholders (company partners and nonuniversity organizations) of the consortia have varied, at least slightly case by case, during the period of PERDA operation. Stakeholder organizations, including the National Technology Agency of Finland, have been funding the PERDA projects. The users of the technological products under research, both individuals (end users) and organizations (service providers), have held special participatory roles within PERDA (Väyrynen, Kautto, & Kirvesoja, 1998).

The following information and communication technology (ICT) products or systems, especially VT, have been studied and developed by these consortia since 1994. A total of 11 case projects have been conducted, dealing with

- telephones, telephone services, mobile phones (multimedia, though primarily voice-only), video telephone, various concepts for diverse industries, and other needs
- video telephone with a touch-screen and a user-friendly user interface (UI), called the HomeHelper
- robotics-style aids for a "smart" home, supporting other ICT products and applications.

The emphasis of the work of these consortia in the last decade has been implementing the concept of ergonomics within the concept and design phases of technology research. Generally, ergonomics introduces a user perspective to design (Pheasant, 1988, 1996). First, *ergonomics* encompasses the empirical physical, cognitive, and psychosocial knowledge of the characteristics of human beings and their activities and experiences. This conventional knowledge of the capacities and limitations of the human being as a user is necessary, but not sufficient. We also must know and understand the needs of users related to their working and living environments and contexts. According to the literature (Hendrick & Kleiner, 2002; Langford & McDonagh, 2003; Wilson, 1995) and our experience, user participation has often had a key role when success has been achieved.

In addition, the field of gerontechnology has played a major role in the research work of the consortia. Gerontechnology was originally introduced in the early 1990s, and is now relatively well-known in all industrialized countries (Bouma, 1994; Fozard, 1994; Harrington & Harrington, 2000). In addition to the design of special products, *gerontechnology* refers to basic and applied research that deals with the interaction between older people and their technological environment. Throughout history, humans have utilized various tools (technologies) to be able to work and live better. Such empowerment by products can be one of the benefits of (geron)technology for the independence and welfare of older citizens. In our cases, instead of gerontechnology, the approach had aimed to guarantee "geronusability" of products (Väyrynen, 2002). This means that often just the UI designed especially for older users is enough to meet the need, instead of designing the whole technological product for older users.

Quite naturally, the traditional textbooks on human factors engineering present guidelines for designing for older users. One example is the list by Sanders & McCormick (1998, p. 77) for designing information processing tasks and ICT products like VTs:

- Strengthen signals—make them louder, brighter, and so forth—for older people

- Design controls and displays so that irrelevant details do not act as distractions
- Maintain a high level of compatibility[1]
- Reduce time-sharing demands
- Provide more time between signals and responses to them or, ideally, let the user set the pace for her/himself
- Allow enough time and practice for initial learning.

The aims of this paper are two-fold: (a) to describe our approach (PERDA) in general, but especially through two practical cases, as well as the main background in the literature; and (b) to evaluate our approach, with some recommendations drawn from the advantages (pros) and disadvantages (cons) of the approach. The evaluation will be based on the entire set of consortia projects from the past decade; this evaluation process will be detailed later in this paper. However, two case studies are provided that highlight the wide participation of individuals and organizations that play a key role.

The first case presented deals with a pilot project for provisioning social, health care, religious, and banking services to older people through a prototype VT device. The second case focuses on the pilot project for a comprehensive technology and service system for older citizens (trials of the VT "pre-product" known as HomeHelper).

PERDA APPROACH IN THE CONTEXT OF THE CONSORTIA

PERDA, as a design approach, is user-centered, which means that the concept of ergonomics and the basic ergonomic system model (depicted in Figure 1a) are key starting points (Pheasant, 1988). The user-centered design of products has many relations to the concept of user-driven products, as opposed to technology-driven products (Ulrich & Eppinger, 2004). Many tools for user-centered design and participatory product development, characteristic of PERDA, are presented by Langford and McDonagh (2003) and Wilson (1995).

However, PERDA also emphasizes the complete contextual system, as shown in Figure 1b. This highlights the importance of the additional components within the basic user-product-task system.

The product development, or tailoring tasks, within PERDA are carried out following the procedure of the 3 + 3 model (Figure 2). This procedure supports the ordinary company-level design and development through research-style activities.

Finally, the consortium of each PERDA project provides empirical material for the user studies and usability studies, with the individual users and organizational users within the consortium piloting the prototypes, pre-products, and products developed. The technology companies use these data to utilize the concepts of new products.

PERDA always starts from the needs and characteristics of individual users, which in our cases consisted of clients/customers and the employees who use these products to carry out the desired tasks, that is, daily living and work activities. In brief, the objective of ergonomics is to achieve, within the interactive system, the best possible match between the product and its users in the context of the tasks (see Figure 1a; Pheasant, 1988, 1996). Furthermore, it recognizes that the interaction between the product and the user takes place in a larger context, which can be described as a balanced (living or work activity) system (Figure 1b).

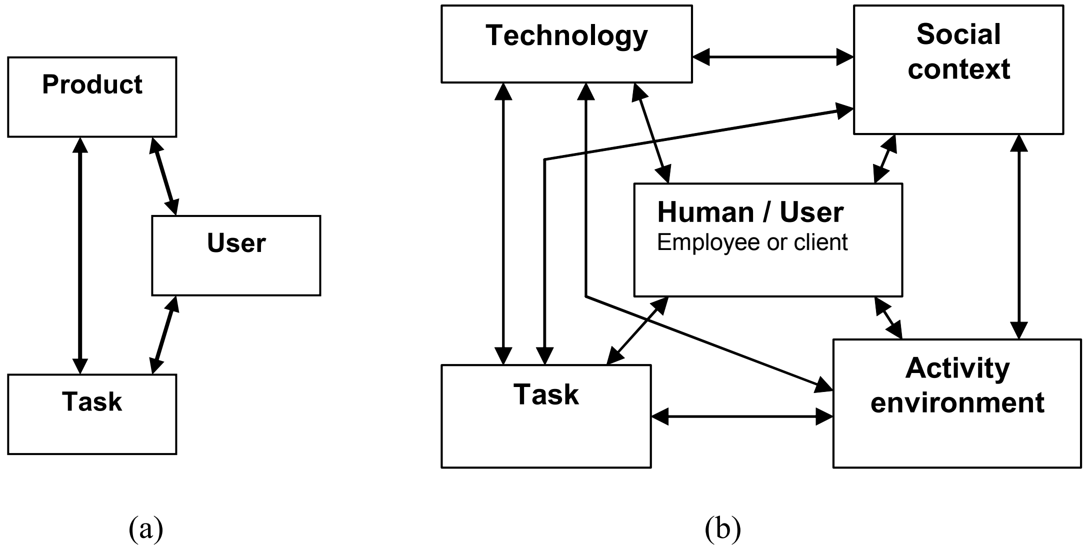

Figure 1. The basic ergonomic system (a) is a user-product-task system (Pheasant, 1996). The extended ergonomic system (b) is an applied modification of the balance model of a work system (based on Carayon & Smith, 2000; Smith & Carayon, 1995; Smith & Sainfort, 1989).

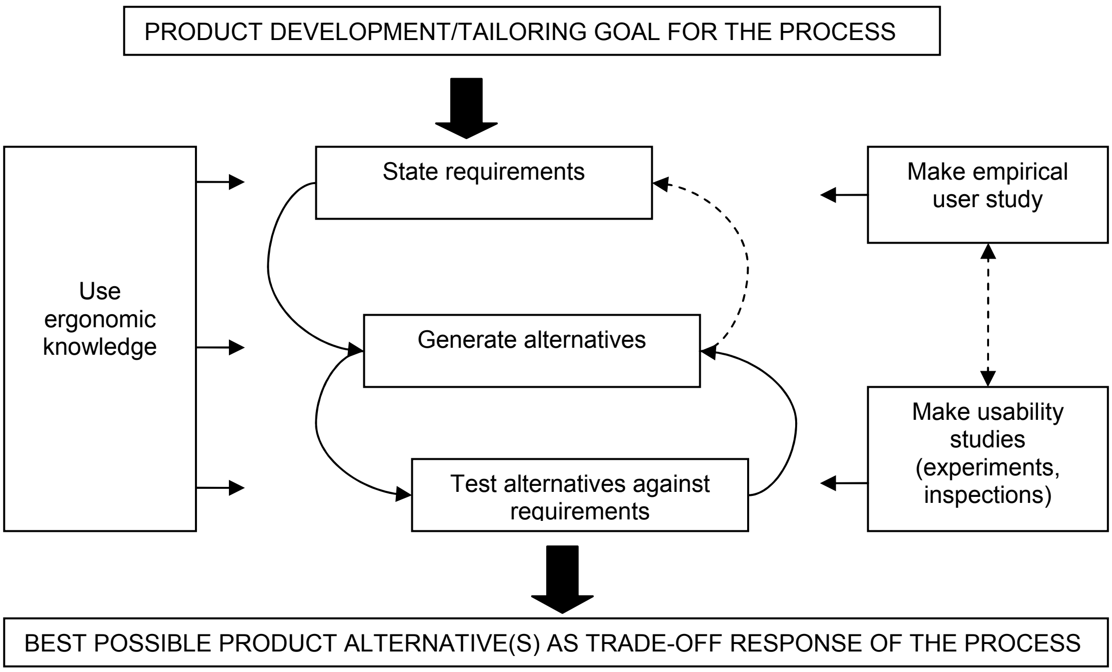

Figure 2. This 3+3 model, in which the three-phase design process is supported by ergonomic knowledge and methods, is an essential part of the PERDA (Väyrynen et al., 1998; Väyrynen, et al., 1999). The rationalistic design is carried out in the processes shown in the center of the figure. The dotted arrows illustrate concurrent engineering potential as well the feedback channel (Tornberg & Väyrynen, 1999). The model is an embedded part of a stakeholder cluster that provides both product needs and possibilities to realize products utilizing technology (Väyrynen et al., 1998).

The role of older users and that of employee users providing services to older users have been characteristic of PERDA because our projects have had close links to the field of gerontechnology.

User-centered design should be an essential part of the contemporary R&D activities within a company. An appropriate amount of relevant knowledge and a robust procedure are needed to create usable, that is user-friendly and useful (Stanton & Barber, 1996), products for markets. The PERDA aims to be compatible for use in industrial enterprises, too.

To facilitate this compatibility, we surveyed technology companies in our consortia to determine the importance of various key product properties (Väyrynen, Törmänen, & Autio, 2002). We asked them about six elements that we thought were essential attributes from the end-users' perspective. The question was, "Presuming that these 6 features comprise a total of 100% of a product, which share would you allocate to each of the features a through f?" The percentage results are listed beside by the attributes and are based on the answers (*N* = 32) received from the technology companies:

a) Number of functions (8%)
b) Price (16%)
c) Industrial design (11%)
d) Technical functionality (19%)
e) Usability (23%)
f) Reliability (23%)

These results are useful to show the importance of usability from the company's perspective. It is clear from these results that the emphasis on usability is not just an academic research perspective.

According to our experiences, usability can be characterized in terms of nine key product attributes (Väyrynen et al., 2002): (a) easy to learn to use[2], (b) effective and efficient when used for tasks[3], (c) easy-to-memorize usage procedures, (d) easy to avoid errors, (e) good physical features of the user interfaces, (f) physically and mechanically compatible with human anthropometric and biomechanical characteristics (e.g., industrial design, mechanical dimensions, mass, center of gravity of the product), (g) easy to avoid health and safety risks (h) easy to implement in the context of use, and (i) able to provide a feeling of high subjective preference (e.g., acceptable appearance and services, pleasant use experience).

Because of the importance of a balanced combination of design features to meet both the physical and cognitive characteristics of humans will remain or probably increase in the future, we found it necessary to add more physical attributes to the often purely cognitive-oriented concept of software or ICT usability (e.g., Faulkner, 1998; Nielsen, 1993; Shneiderman, 1998). Changes in technology appear to support this conclusion, because (a) software UIs are increasingly being embedded in traditional products, such as machines and daily service systems, and (b) mobile ICT is becoming more popular as compared to stationary PC-style workstations.

Our own user-centered design process model, which is an essential part of PERDA, includes three elements: ergonomic knowledge, a user study (Tang, 1991; Wiklund, 1995), and a usability study (Figure 2). These three approaches are combined with the three "purely" technological phases of traditional and rational design. This 3 + 3 model (Figure 2) has been utilized in our R&D projects along with an experimental and participatory emphasis and traditional expert-oriented evaluation.

Within the 3 + 3 model and the PERDA, each combination of technological and UI solutions composes a product alternative that possesses a certain total "goodness" when compared to the multiple criteria of requirements (Pahl & Beitz, 1988; Väyrynen, Kirvesoja, Kangas, & Tornberg, 1999/2000). In other words, these product combinations comprise the best trade-off responses in fulfilling the 3 + 3 process shown in Figure 2.

The following details and comments are aimed at characterizing PERDA further. The definition of the user profile is an important part of a user study, as is the task analysis to define needs (e.g., What will the user/operator actually do with the application/product/system in development?). Observation, inquiries, interviews, and the focus group technique are used to collect empirical field data (Wiklund, 1995). An effective user study is an important basic tool for preventing a mismatch between the product and user requirements and, hence, for promoting final usability.

Usability studies help elaborate the design alternatives, or concepts, initially identified through requirement specifications based on the user studies. Usability studies are an indispensable part of the ergonomic approach: They are used to identify, observe, and measure the interaction between the user and the product in assessing usability. Measuring the interaction between the users and the products is the fundamental principle that underpins all ergonomics (McClelland, 1995). A user trial—the most common type of usability study—is an experimental investigation in which a group of users interact with a version or versions of the product under controlled conditions (Pheasant, 1988, 1996).

A cooperative usability study, where the designer and the user together analyze the product in the different phases of the iteration process, is a promising new alternative (see Figure 3a). Generally, user and usability studies help in discovering costly design errors soon after they have been made, and facilitate the implementation of new technologies. In addition, a user-centered, participatory approach like PERDA makes the users feel that decisions are being made not only for, but also with, them. Resistance to or disappointment in new products, such as tools, can be prevented or alleviated. Participation optimally takes place at both the organizational and the individual levels (Wilson, 1995). Thus, for instance, both top-down and bottom-up approaches (Deschamps & Nayak, 1995) can be utilized.

Descriptive studies yield useful information on general human characteristics, abilities, and limitations, as well as the users and usage of various products. As far as usage, needs, and conditions of use are concerned, various studies and documents are available for user studies. One method that has proved useful is the focus group (Langford & McDonagh, 2003; see Figure 3b). To be effective, the expert guiding the focus group must present all of the users' requirement specifications drawn from various data sources. One possibility to achieve this is through the use of a multicriteria, often hierarchic, weighted structure in presenting a product's key features, among them usability and safety requirements based on ergonomics. These would represent the criteria that form the overall goodness of the product (see Table 1).

In the strategy of contemporary companies, managing innovations is a key to productivity and growth (Kaplan & Norton, 2004). A culture of creativity and innovation is promoted. To promote creativity in participatory procedures, our PERDA study teams have used various techniques in recent projects, especially brainstorming and the OPERA method, which is a special form of brainstorming with multiple phases (Mikkonen, Väyrynen, Ikonen, & Heikkilä, 2002). Based on our prior experience and the literature, we also have developed a new method, known as the user game, for identifying user needs. This game and story-assisted user study integrates a focus group, a group interview, and observation into one flexible and

(a) (b)

Figure 3. The design process—specifically the user studies and the usability studies within PERDA—can be characterized by frequent, direct contact with the people who are potential users of new products. One new form of interaction with people is to have the researcher/designer and an older end user cooperatively go through the design alternatives (a). Image (b) shows a focus group consisting of representatives of service staff and researchers involved in a demonstration with prospective users regarding how the technology meets their needs (Kirvesoja, Sinisammal, Väyrynen, & Tornberg, 1999). In this particular situation, the service provider used the VT to provide medical training on diabetes. This focus group also followed the nurse's lecture and assessed how the information and process was being grasped by the elderly participants. Both (a) and (b) are linked to the first phases of conceptualizing and prototyping the VT system called HomeHelper. The VT set in (a) was a late-stage prototype of HomeHelper whereas in image (b) a TV set was used as VT monitor. The use of a TV set was typical of the VT process in our first case presented here.

Table 1. Multicriteria Requirements Assessment Model for Video Telephony (VT) Devices.

Criterion definition	Proportion (%) representing the weighting factors, that is, the relative importance of each criterion
VIDEO	
Seeing (bidirectional)	20
Showing (bidirectional)	12
AUDIO	
Hearing (bidirectional)	15
Speaking (bidirectional)	10
CONTROL	
UI software	10
Input devices	15
CONFIGURATION	
Postural effects	4
Physical features	10
Appearance	4
Sum of the weights	100

Note: The weights of each of the nine criteria as a share of the total overall "goodness" of VT can be defined empirically or as opinions of experts. The latter was the source of these criteria and weights. (Pahl & Beitz, 1988; Väyrynen et al., 1999/2000; Väyrynen & Pulli, 2000).

quick method that can be used to gather information from a relatively large group of users (see Figure 4; Härö, 2003; Tamminen, Riekki, & Väyrynen, 2001). To our knowledge, no such method for identifying the needs of older people has been suggested earlier.

In this method, the older people play a board game and tell stories under the guidance of one or preferably two researchers. The aim of the user game is to give the participating older subjects (aged 65+) a feeling of experiencing a situation by visualizing environments with a map and photos. This feeling helps them to remember details of the situation, which, in turn, helps them and the researcher to identify real needs in the first phase of research, that is, during the user study, as well as to invent solutions to meet those uncovered needs in the second phase, that is, during alternative solution generation.

Experimentation with alternative products, prototypes, or early concepts mainly includes usability tests. The test trials may be field experiments (Figures 5 and 6) or laboratory simulations (Figure 7). Requirements specifications (e.g., Table 1) and checklists help experts make heuristic usability evaluations using inspection methods, for example by utilizing literature guidelines and the designer's expertise and experience (Nielsen, 1993).

Figure 4. The so-called user game enhances data collection during a user study by providing topic triggers for recollection and/or description of activities. This image shows the first phase of the game being played in which an older player explained how she performs a typical daily activity (Härö, 2003; Tamminen et al., 2001).

Figure 5. In this field trial of video telephony, an older client in her home was showing to a physician at a health care center, via the VT service, the condition of her ankle (Kirvesoja, Sinisammal et al., 1999). A TV set was used as a VT monitor during this case.

Figure 6. Some user trials with touch-screen-operated video telephones were carried out at an older individual's home. This technology allowed the client to make video calls to her friends, relatives, or service providers.

Figure 7. Industrial designers from the University of Lapland experimented with concepts and UI features of videophones by constructing a realistic wooden mock-up.

PERDA CASES

Within our ergonomic and gerontechnological framework, several ICT applications (devices, systems, software, services, content) have been under special consideration. Many products, technologies, and systems have been developed, described, and assessed in detail. Table 2 shows the basic features of our 11 cases.

Table 2. The Primary VT and Closely Related Case Projects by the PERDA Consortia.

Technology (product & service)	Research foci: User versus Product / Activity / Task / Work / Process	Figure number	References
A) Telemaintenance of technological production systems in industry	Remote working support, telepresence, information transfer, shared expertise		Väyrynen & Mielonen, 1994
B) Telemedicine: VT remote psychiatric consultation	Sparsely populated areas, long distances, communicating effectively without traveling, feeling of being face-to-face in communication		Oikarinen, 1998
C) Industrial machinery maintenance tasks using VT	Providing special expertise to remote industrial sites via on-line video communication		Kautto, Väyrynen, & Kirvesoja, 1997; Kautto et al., 1998
D) VT as a tool to provide home services for the elderly (started in 1995)	Health, banking, and religious services, some pilots via ISDN video communication, UI design	3 b, 5	Kirvesoja, Sinisammal, et al., 1999, (see Case One)
E) Concurrent engineering-type activities in manufacturing via VT	Product developers and designers communicate with remote prototype manufacturing		Tornberg & Väyrynen, 1999
F) Telephone services, mobile phone services (mainly voice)	Voice interface, hearing and speaking, cognitive factors		Pirinen et al., 1997; Mikkonen et al., 2002
G) Multimedia home aid communication (mmHACS) via VT to provide diverse services and contacts	Sensing, cognitive processes, manual control / UI, especially audiovisual displays & input, touch screen	3 a, 6, 7	Ikonen, Väyrynen, Tornberg, & Prykäri, 2002; Riekki, Röning, Väyrynen, & Tornberg, 2000

H) Video telephones in telemedicine,	Implementation and usability issues, cognitive, physical, social, organizational factors, patients and personnel as users	8	Kirvesoja, Oikarinen et al., 1999; Väyrynen et al., 1999; Väyrynen & Pulli, 2000; Väyrynen, Törmänen, Tornberg, & Prykäri, 2001
I) (Ge)robotics	Cognitive processes, sensing, UI, safety, compatibility with the home, remote control via VT, telepresence		Riekki et al., 2000
J) Wheel walker with ICT support (ÄLLI)	Mechatronics, embedded ICT, physical and cognitive UI, outdoor application, navigation, VT	4, 9	Tamminen et al., 2001
K) Video telephones in a municipality and location-based services for providing diverse services	UI, usability evaluation methods, user experience, new services, field conditions	10, 11	Röning, Alakärppä, Väyrynen, & Watzke, 2005; Alakärppä, Röning, & Väyrynen, 2005; Rusanen, 2004; Väyrynen, Röning, & Alakärppä, 2005 (see Case Two)

In all of the cases studied through our research consortia, a fairly large number of end users and managers of utilizing organizations were involved. Both private companies and public sector partners were involved as suppliers of various services. Both service sector employees and clients/customers (e.g., physicians and senior citizens) were actual users. Indirectly, however, the managers and the organizations as a whole were often involved especially as far as the implementation of new tool is concerned (Figure 8). End user applications were most often aimed at indoor use but the cases comprised mobile product facilitating outdoor use as well. The latter ones were not only mobile phone-based (see Mikkonen et al., 2002) but the cases included one with a wheel walker basis for embedded ICT (Figure 9).

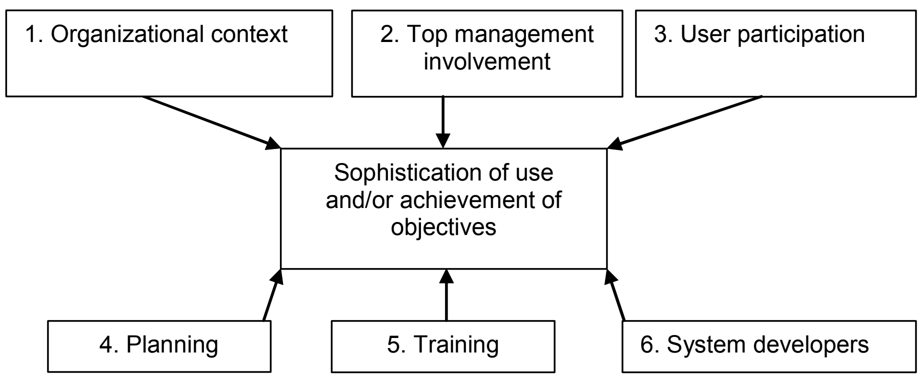

Figure 8. In addition to concrete product models used in the study, abstract operational models were used, for example, to demonstrate a successful approach to implementing technology into a user organization (based on Majchrzak et al., 1987). This model was utilized when new telemedicine technology was introduced into the Central Hospital of Lapland and in the entire Lapland Hospital District (Kirvesoja, Oikarinen, et al., 1999).

Figure 9. Mobility aids for older people were equipped with a multimedia terminal, making positioning-based outdoor navigation support possible. The project developed products and services to support the independent coping of older citizens. The ÄLLI project (Table 2, Technology J) concentrated on walking aids, user interfaces, and service concepts.

Case One: Piloting Services via Video Telephony

This case involves several pilot VT studies, conducted from 1995 to 1997 (Kirvesoja, Sinisammal, Väyrynen, & Tornberg, 1999). These studies had their roots in some aspects presented within the literature, in the global and local progress of telecommunication, and in some earlier experiments (Väyrynen & Mielonen, 1994). VT services may be a more cost-effective form of care than either institutional care or domiciliary visiting services (Gott, 1995), and this has been one of the most important reasons for providing services via VT to elderly and disabled inhabitants in industrialized countries. In Finland, the first experiments of this nature were started in the late 1980s (Perälä, 1993).

A European evaluation of the pilot video telephony-based services for elderly and disabled people reported that older users liked the video telephone service and wanted more of it (Research and Technology Development in Advanced Communications Technologies in Europe [RACE], 1993). The service providers were also satisfied with the pilot test.

Field Studies

For the field studies, the consortium involved primarily local partners. Videra Ltd., a manufacturer of VTs, provided the technology, and researchers from the University of Oulu carried out the trials and other experiments. The purpose of this field experiment was to acquire practical experience on the applicability of VTs in providing social, health care, religious, and banking services (Table 3). The public sector partners in the project were a city and a municipality. Personnel of a local church quite briefly tested the VT system in view of developing the conventional practices of spiritual and pastoral care. A bank cooperated in a brief experimental use of VT for banking transactions. A VT system was also used to transmit sign language messages. In addition, service providers participated with researchers in several focus groups concerning the potential for and the development needs of VT (see Figure 3b).

Table 3. Participating Organizations in Case One.

Organization	Personnel	Clients
City of Oulu:		
Home Care Service of Southern Oulu	28	1,379
Interpreters' Center in the City of Oulu Handicapped Service Unit	4	137
City Service Center	10	735
Runola Home for the Deaf	30	56
Oulu Association of Evangelic Lutheran Parishes	210	100,000
Municipality of Tyrnävä:		
Home Care Service	14	124
Lepola Rental and Service Flats for the Elderly	4	58
OKO Bank, Tyrnävä	7	3,200
Tyrnävä Health Care Center	20	4,200

Each organization took part in the trials with a small sample of personnel and clients.

Elderly participants, home care workers, and other service providers were either interviewed or they filled out a questionnaire based on the interview questions to gather background data and opinions on the VTs. After the trials the people involved filled out a second questionnaire. By gathering opinions both before and after the experimental trials, we could reveal the influence of experiences. Deaf participants in a different phase of the study were asked their opinions only after the trials.

An experimental field setup was used at various service flats for the elderly in Oulu and Tyrnävä (Table 3). The home care staff operated the VT system and the elderly subjects communicated usually as groups of a few members with the different service providers. Researchers gave instructions to both the staff participants and elderly participants and observed the trials. A total of 22 elderly subjects participated, involving an equal number of males and females. Their mean age was 72.5 years. The experiments included remote appointments with physicians, a dental hygienist's presentation of oral hygiene, a presentation by home care service workers regarding themselves and their work, a presentation by social workers' regarding available services, and a public health nurse's lecture on diabetes (cf., Figure 3b). In addition, one patient held a more thorough VT consultation with a physician concerning the treatment of leg ulcers (see Figure 5). For bigger groups, demonstrative trials with VT and descriptions of potential use scenarios were carried out as far as banking and religious services were concerned.

In another field setup, 20 deaf or hearing-impaired subjects, most of them middle-aged or older, tested the video telephone, usually as groups of a few members. Several realistic situations were simulated and several activities, services, and instruction-giving settings were tested. Various sign language discussions by deaf subjects via VT and the provision of spiritual and pastoral care to deaf subjects by church workers were carried out more systematically.

On the provider side of the experiments, a total of 40 representatives of various professions were involved. The most frequent occupations represented in this phase of the experiments were home care workers (n = 20), nurses (n = 4), and physicians (n = 3).

Results

In the field experiment, the VT contacts regarding health care and social issues between the staff and the elderly subjects were notably active. The subjects asked a number of specific questions concerning their health. However, when leg ulcers, rashes, scabs, and bruises were evaluated over the VT, it turned out that the two-dimensional view was inadequate. Illumination and correct reproduction of colors also appeared to be of notable importance. Because the experimental connection with the bank was brief and the timing was not good, it was not possible to elicit the elderly persons' experiences with banking. So too was the specific feedback regarding the religious services limited because of the brevity of the trial.

Before the experiment, 64% of the elderly subjects believed that the use of VTs would increase in the future, while the corresponding percentage after the experiment was 75%. Before the experiment, only 18% of the elderly considered the VT to be easy to use, while 50% gave such an assessment after the experiment. The best benefits of the VT system assessed by the elderly were the visual contact and the possibility of establishing a connection easily and quickly. It was further pointed out that VT greatly facilitated the lives of persons with limited mobility, and VT contacts were even compared to in-person visiting and thus considered a means to alleviate loneliness. Practically the only perceived drawback was the high price of the VT set.

Only 55% of the deaf subjects, who were users of sign language, were able to read or write Finnish. But, after the trial, 90% of these participants believed that VTs will become an increasingly common tool for the deaf. Only two subjects (10%) had previous experiences with VT. However, 65% considered the VT to be useful in their daily activities, and 85% evaluated its use as easy or relatively easy. Sign language conversation over a VT was thought to be moderately successful by 55% of the subjects, and nobody found it difficult.

Eighty-eight percent of the various service providers were female. Their mean age was 37.7 years. No previous experience with VTs was reported by 95% of them. The majority of respondents found the VT a practical, useful, and even a moderately good tool (Table 4). As many as 70% of the service providers said that the VT met their expectations the first time they used it, and 25% said they met no difficulties concerning the use of the VT system. However, some had difficulties in using the mouse and focusing the image. The twitching of the image was considered unpleasant, and system management was difficult whenever there were problems. Ease of use was considered the most important characteristic by 40% of these service providers. Visual contact ranked second, followed by the ease of establishing the connection, a clear image, and simple operation. The greatest potential of the system was considered to be the decreased need to transport elderly people and the consequent savings in cost and time, as well as the improved living conditions of the elderly subjects and the working conditions of the home care workers. The VT was also considered a useful tool in home nursing as well as in remote medicine, consultation, and negotiations via remote medical service. In the banking business, services of which were only briefly trialed and discussed during these field studies, the major uses of VTs were seen to be in information service, negotiations, marketing, and product presentations.

Table 4. Overall Evaluations by Service Providers of the VT system.

very poor		OVERALL RATING					very good			
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**no opinion**	**mean**
0	0	0	0	3	10	17	**53**	17	0	**7.4**
unnecessary		OVERALL NEED					necessary			
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**no opinion**	**mean**
0	0	0	0	9	6	14	**40**	28	3	**8.1**

Note: $N = 40$; the data are provided in percentages, based on responses to a 9-point scale.

Discussion

According to this experiment, VT is likely to be most beneficial in contacts for the home nursing and home care staff as well as the health care center personnel. Physicians, public health nurses, and clinical nurses are clearly better able to evaluate an elderly client's health status and need for an office visit over a VT than over a conventional telephone. This will help to decrease the number of unnecessary visits.

A VT system would allow deaf persons to communicate in their native language. Increased use of such systems would notably increase their capacity to communicate with service providers and other deaf people, and even relatives, with sign language. Many of the deaf have inadequate reading and writing skills in the majority language and are therefore unable to benefit from a text telephone. Sign language interpreters could similarly use the VT as a handy tool.

VT also seems applicable in at least some banking business. The need for absolute confidentiality continues to be a problem, however. It is still necessary to solve the problems of reliable client identification and the transmission of electronic signatures over a VT connection. But preliminary negotiations for a loan, for instance, are easy to carry out, provided the client turns up in person to sign the papers. VT systems might facilitate personal banking by people with limited mobility. Investment counseling and some other services are also easy to provide over a VT system.

Case Two: Services Brought Home via an Internet VT System

The second case presented here is the most recently completed case, and deals with technology and services aimed at older users in a municipality context. Thus, it is comparable with Case One discussed above, which was a large and sufficiently long-lasting study of VT. Improvements in the technology include, in particular, the HomeHelper UI, the displays, and the capacity and speed of the network. A requirement model of VT that describes a combination of multiple criteria for good product (see Table 1) has been an important tool for assessing progress in the details and overall goodness of different versions. Case One had already provided many ideas and needs to be developed, as did the many subsequent iterations. The ICT infrastructure and acceptance of ICT by people have been developing as well over the past decade.

The principal objective of this most recent project (see item K in Table 2) was to improve the daily functions of people of older ages and to promote well-being and safety through the possibilities of new technology (see Röning, Alakärppä, Väyrynen, & Watzke, 2005; Rusanen, 2004). So the focus was not only on VT; other ICT possibilities were screened as well. The project emphasized usability, interaction, enjoyment, and a positive experience with use, and it sought answers to three questions:

(a) What services made possible by ICT can support the elderly in living at home?
(b) What kinds of services can be smoothly integrated into a VT system?
(c) What is the usability of the services via VT developed?

Field Studies

A quite sophisticated VT system, called the HomeHelper, was tested in the form of a "pre-product," that is, a late-stage prototype, followed by long-lasting utilization of the procedure of Figure 2. Services that older users need were discussed and evaluated with the personnel of various service providers in the municipality of Ristijärvi, Finland.

During the starting phase of the project, the older users' needs—an important part of the user study—were collected and arranged in a table based on their estimated importance. Rating system for importance involved assigning points according to the following criteria:

1 point:
- the need is mentioned only by one source
- the need has not been considered very important by those who raised it

2 points:
- the conclusion of the need's importance by a researcher or an expert group
- most of the service providers or older people consider the need to be important

3 points:
- need was very frequently stated by the older people.

The needs for different services that arose from this weighting process were ranked in the following order: Safety, leisure, shopping, health care, memory aid and information, transportation, navigation in unknown places, and banking services. These needs, then, were considered priorities.

Based on both the discussions and ranking, three remote services were chosen for the trials: (a) a health care center (health care professionals assessing and discussing the health status of the elderly), (b) a local church (the elderly viewing a religious service transmitted to their residences), and (c) shopping (the subjects' choosing and buying retail products from shops using a video connection).

Trials were carried out in two test locales, the municipality of Ristijärvi, Finland, and Vancouver, Canada. The technical test setup of the system is shown in Figure 10. The Canadian results have been reported only partially, and mainly in the Finnish language (Rusanen, 2004). Detailed reporting will be provided later, but principally the results of the Canadian study are in line with those of the Finnish study. Therefore, this article will address only the results of the Finnish study site.

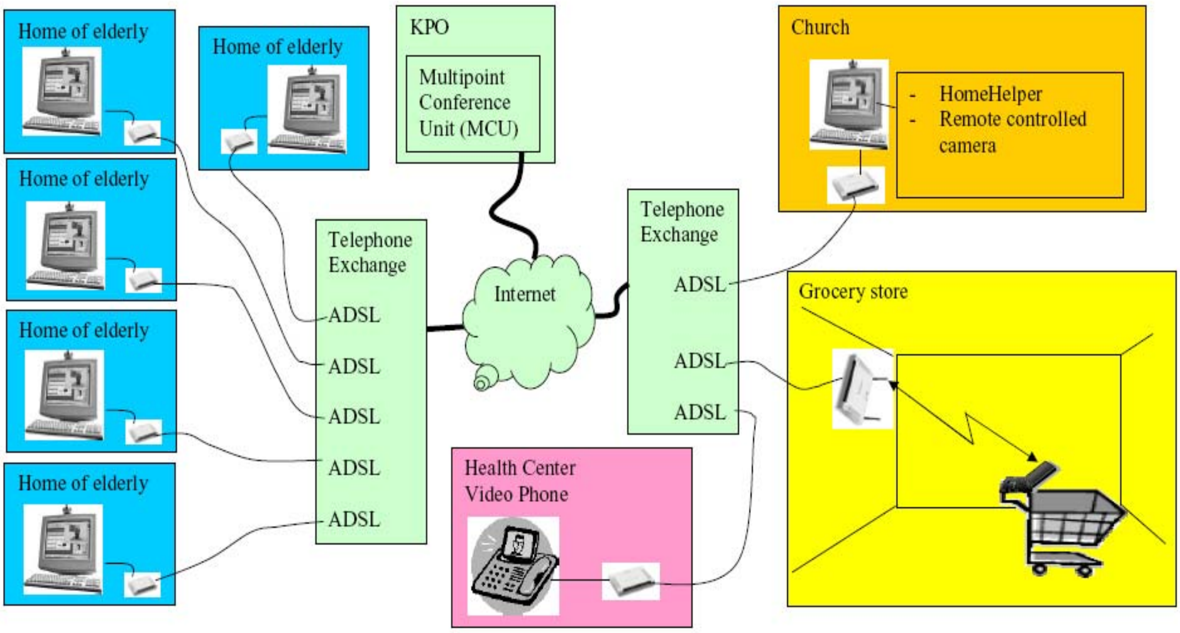

Figure 10. This illustrates the test setup in Case Two, Ristijärvi, Finland. The HomeHelper VT devices, as part of an integrated system, were used in homes (left) and the HomeHelper VT and other VT technologies were located at service providers.

Ristijärvi is a small Finnish rural municipality in the Kainuu region, with a sparse ($N <$ 2,000), quickly "graying" population and long distances to a relatively small variety of services. Available services consist mainly of public health and social services.

A group of older adults from Ristijärvi were introduced to a set of broadband wireless daily living communications technologies that compose the HomeHelper (HH) VT, a system of which there were three kinds of home devices (Figure 11). The main goal of the usability study was to gather input from older adults regarding the usability, relevance, and potential of such a system in terms of their daily needs. Ideally, this system of technology would provide improvements in the quality of life of the seniors, especially those who are frail or isolated.

The service provider users group consisted of the personnel of (a) public health services in the municipality's health care center, (b) a local majority religious congregation, and (c) a local grocery store. The personnel collaborated with the researchers to establish suitable service provisions for the trials of the HH system carried out in field conditions, both at the service providers' locations and in the homes of the older customers.

The case involved two independent studies. The first involved test trials in which older users (N = 5, 3 males, 2 females; mean age 66.4) had an individual on-line connection providing each of the three services (health care access, religious liturgy, and on-line shopping). The second study comprised focus group discussions with eight seniors other than those involved in the HH system trials. They were tasked with evaluating the process of peer tutoring, and of assessing three concept variations of VT sets (see Figure 11) that were potential alternatives to the HH for providing a system of daily living services for older users.

Figure 11. Various monitors, including TVs, and other components of the VT system were studied throughout the duration of the VT cases. Most recently (Case Two), the HomeHelper terminal device concepts, most of them at the “pre-products” stage, were tested. From the left: a special videophone set, a tablet PC, and a desktop PC.

The main foci in the trials were

(a) to observe and record the users’ first impressions of the services and the HH devices,
(b) to evaluate the instructions that were written by researchers to facilitate independent operation of the HH,
(c) to observe how often the users came to situations in which they could not independently operate the HH,
(d) to evaluate the acceptability of the HH as a technological product,
(e) to study how often and what kinds of errors were met during operation of the system for service provision,
(f) to determine if it was possible for the users to use the HH system in a time-efficient manner, which particularly concerned the usability of HH UI, and
(g) to ask the users to rate the HH system and services on a semantic differential scale as far as usefulness, general ease of use, and feeling of use.

The focus group study concentrated on the opinions of the feasibility of the HH system. Various devices were viewed, researchers described the devices and scenarios in which they could be used, and the opinions and ideas of the older persons were sought regarding the potential use situations. Some of the subjects acted as peer tutors and instructed the rest of the subjects on the use of the HH system. The members (N = 8) of the instruction group then ranked the HH devices based on their experienced opinion regarding the total goodness and usability of each device.

Results

While the data from this case are extensive (see Rusanen, 2004), only a portion of the results can be included in this paper. The usefulness of the possibility to carry out the grocery shopping via VT scored 4.0 on a semantic differential scale (1 = *really useless*, 5 = *very useful*). The corresponding score the seniors gave for being able to shop without feeling pressured or hurried unpleasantly was 4.4. When debriefed, the users reported finding the HH shopping experience pleasant, natural, and genuine. The respondents declared that the usefulness and practical value of HH e-shopping would increase as their personal health declined. They also recommended this service for younger users with musculoskeletal disabilities.

The usefulness of health services was scored 4.2 on the same semantic differential scale described above. The score was the same when asked, "How did you find discussing your own health issues via the HH?" All the users felt secure and confident in discussing intimate health issues by utilizing the remote HH. Additionally, pharmacy services were suggested as having positive potential in further trials.

The local church service was generally less appreciated via the video telephone compared to the other two test activities (usefulness score = 3.4), even though the pleasantness of participating from home was scored 4.4. The respondents reported the HH-based church service from their congregation seemed too much like watching a generic service on TV. Furthermore, according to these elderly participants, the feelings of one's own congregation and own church could not be experienced when using remote teletechnology, such as the HH.

The general ease of use for the system was scored 5.0; operating the touch screen, 4.8; navigating between levels on the UI, 4.8; and making video calls, 4.6. However, the important technical features in video telephony—the quality of picture and voice—were scored 2.8 and 3.0, respectively. Thus, the weakest aspect of the HH concept was the technical level of the displays, that is, the screens and loudspeakers. Of utmost importance from the overall results, nevertheless, is that the older users were satisfied, on the whole, with the service concepts developed for the HH system. And in principle, they found the HH to be both easy to use and a useful device.

During the focus group discussion, the following aspects of the lives of older people were emphasized: health care, bank services, commuting, living alone, and the role of computers. The HH system was thought to be able to positively affect all the above areas. However, the principal positive attitude toward adoption of the HH system also included many preconditions, for instance, provision of proper and diverse services, costs, ease of use, and overcoming a phobia toward computers and HH as well. Yet, many positive social consequences, such as more frequent contacts with family members, privacy, and security, were acknowledged. The last two issues were of the least concern by the older subjects when the future possibilities of HH system were discussed.

The group of eight seniors tasked with assessing the three options for HH devices provided their feedback after using the products to inform other seniors about their use. They ranked the HH devices in the following order of preference: a special videophone set, a tablet PC, and a desktop PC (see Figure 11).

Discussion

This study, although modest in scope, proved to be a successful pilot project in determining the user-friendliness of the further developed HH VT system. Further larger-scale testing is now in order, with higher demands on the verification of the reliability of trials and validation of measured results.

Due to the small size of the sample of subjects, however, the scientific significance of the project is limited. Therefore, we feel the sample size of seniors that are exposed to this type of technology must be enlarged. In addition, a great variability of needs exist within the aging population, even within a single culture/country. Thus, to properly investigate the potential of such a technology in seniors' daily lives, we would recommend a much larger applied field study, for example, where a number of HH prototypes are set up in public settings, such as senior centers, churches, or dining halls of seniors' housing complexes. These obviously would be useful for making it possible for seniors to get acquainted with VT system, in general, and with some of the accompanying services and other end-user devices. Many of the services via VT, though, are relevant only under conditions with privacy.

A second area of research we feel would be beneficial to the HH development is a more detailed study regarding the adoption of such technology by senior citizens. As we have seen with other research, the adoption of new products by older users is restrained by the importance of their rituals (Ikonen, Väyrynen, Tornberg, & Prykäri, 2002). The challenge of encouraging seniors to embrace new technology can apply to the HH system. The HH system would need to be perceived as useful for and used by all aged persons, so as to remove the stigma of aging and frailty. Related to this line of research, we feel one of the best ways to alter the negative or stigmatizing perception of a device intended for seniors is to engage family members (and caregivers) in the training and adoption process. One could imagine a set of usability studies with the HH system that would require sons, daughters, and spouses to be active participants in the study, for example, each member of the family would agree to use the HH for his/her own chosen daily living activities. We hypothesize that having the whole family involved would lead to greater adoption by the older adults.

EVALUATION OF THE PERDA APPROACH

The Methods of Evaluation

The method of evaluation comprises mainly the principles and practices that utilize balance sheets, a SWOT analysis, a force field analysis (Langford & McDonagh, 2003), a PDCA or Deming cycle (Hutchison, 1997; Logothetis, 1992) of improvements, and, of course, benchmarking (Hutchison, 1997; Logothetis, 1992) as well as other well-known tools of quality management, especially TQM (total quality management; Hutchison, 1997; Logothetis, 1992). Balance sheets are composed of a list of pros and cons. A SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis often helps when a general evaluation has to be made and illustrated. A force field analysis helps identify the factors that are helping or hindering the achievement of a desirable outcome. The relative strengths of the forces are usually marked either as scores or as arrows with different lengths.

A PDCA cycle represents the continuous notion of process improvement that starts with a planning (P) process. This is followed by a limited trial, represented by the do phase (D). After limited deployment, the process is evaluated using a check (C). This indicates whether the process needs modification before full deployment, the act (A) cycle. An evaluation of one's own process performance against benchmarked (good) practices or other comparative information or data is nowadays very common in any organization.

Outcomes of the Evaluation

The first method of evaluation used in assessing the PERDA research and the actual research projects was a balance sheet of the pros and cons, the positive outcomes and the problems or negative outcomes, of each case within the decade-long period of research. Table 5 provides one pro and one con from each of the research projects detailed in Table 2.

Table 5. Principal Balance Sheet for Case Projects by the PERDA Consortia.

Technology (product &service)	Pro	Con
A) Telemaintenance of technological production systems in industry	Promising start in a university laboratory	Only principal trials without a specific immediate future plan
B) Telemedicine: VT remote psychiatric consultation	First evidence that VT technology works in real tasks (meetings) to overcome long distances	Only training and consultations among professionals without involving patients (clients)
C) Industrial machinery maintenance tasks using VT	Portable field device with some efforts to tailor the user interface	Interest of maintenance companies limited mainly due to network and other technological problems
D) VT as a tool to provide home services for the elderly	Positive participatory experiences at the municipality level with some public and private remote services	Problems with the ISDN network limited possibilities to extend and continue trials
E) Concurrent engineering-type activities in manufacturing via VT	Virtual office concept, made possible by VT, supported concurrent engineering within the design and prototyping departments of a manufacturing company	Too little emphasis was placed on the quality of the terminals (cameras, microphones, monitors, loudspeakers)
F) Telephone services, mobile phone services (mainly voice)	A quite challenging tailoring of the UI needed for older users was realized	Shopping and other services were not ready to be utilized by voice-controlled automatic phone ordering system
G) Multimedia home aid communication (mmHACS) via VT to provide diverse services and contacts	VT as a unique prototype called HomeHelper with a "very easy" touch-screen-only UI could be iteratively constructed	Success with the VT terminal could not be supported by a service provider or network
H) Video telephones in telemedicine	Large-scale implementation of telemedicine (e.g., video-consulting) by a large user organization was first modeled and then realized	User-centered optimization and tailoring of technology was limited due to the purchasing policy of the organization
I) (Ge)robotics	Vision of possible synergies of a VT connection via the Internet and helping telemanipulation with remotely controlled mobile robots	Robots were seen by some individuals and organizations as "enemies" of direct human services, care, and contacts
J) Wheel walker with ICT support (ÄLLI)	A specially designed wheel walker was outfitted with ICT facilities (own UI with VT, mobile [video]phone, navigator, personal digital assistant [PDA])	Ownership of idea and utilization of a "mechatronic" product prototype caused confusion between ICT and mechanical company partners within the consortium
K) Video telephones in a municipality and location-based services for providing diverse services	The creation of an integrated, user-friendly VT system known as the HomeHelper that provided accessibility to a broadband Internet network, fixed or WLAN (Wireless Local Area Network), and a variety of public and commercial services proved to be beneficial and could now in principle be implemented by individuals and organizations within society	Big questions remain: Is the ICT infrastructure capable to meet the system's needs? and Who will pay for VT products and services (individuals or society)?

Only one pro and con is provided per case: This table corresponds to the information found on Table 2.

Many factors—some helping, some hindering—have affected the 10-year research and development of the use of VT for older users. The most important factors are illustrated in Figure 12 as force arrows pushing in opposite directions. Naturally, the helping forces need to be strengthened to make it possible for us to achieve the target of "where we want to be" through PERDA, and the hindering forces tempered. This way we could close the now existing gap between the current state and the desired end-state.

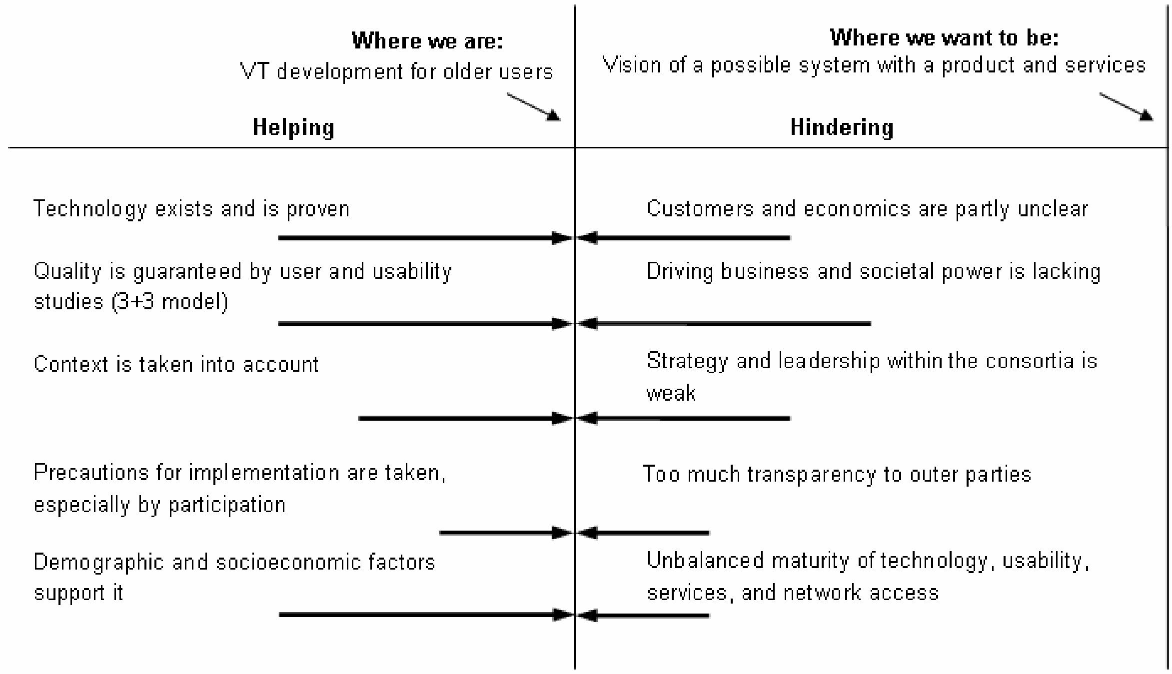

Figure 12. This force field analysis shows the main factors identified by the authors that helped or hindered achievement of the goals in the VT R&D approach. The arrows on the left represent the forces helping while the arrows on the right represent the forces hindering the process of reaching the target of "Where we want to be." To reach our goal, we have to enhance the helping factors while simultaneously diminishing the hindering ones, thereby moving from "Where we are" towards the target.

PERDA was evaluated by the researchers applying it. A short self-audit was made by use of the SWOT method (Figure 13). In this application of a SWOT, the strengths and weaknesses were based on past experiences and the current situation, while the opportunities and threats dealt with future views. Compared to the force field analysis of Figure 12, the SWOT was able to equip us with more refined analysis categories. The SWOT shows the complexity of the VT R&D field. The needs and possibilities, time and resources, and individuals and contexts make the playing field more demanding.

Part of our idealistic 10-year mission that motivated these developments was to empower older people by means of (geron)technology. Some ICT solutions, including VT, are being applied currently at the regional and municipal level. Telemedicine is the clearest example (Kirvesoja, Oikarinen et al., 1999; Oikarinen, 1998). However, many technical applications

Strengths	Weaknesses
• Multidisciplinary • Cooperation with a research consortium • Know-how about the field (context) • Voice of end users is heard • Small and medium-sized companies able to participate • Public and private sector developing new services together • Dissemination of user-centered design to participating companies • Wide communication and interaction	• No holistic system under development, just sets of devices/services • Lack of wide cooperation with other research groups in Finland • Laborious, time-consuming approach • Transparency to outside parties • Links to quality management within organizations too weak • Verification and validation reviews were not clear enough • Weak links to economic assessment
Opportunities	**Threats**
• More important and bigger organizations could participate • Significant cumulative know-how and competence for wider systems with diversity of services • Generation of new enterprises based on gerontechnology and ICT • Increasing positive attitudes toward changes and implementation of new technology • Methodological experiences with older users can be generalized to all users • Optimal compatibility with other parts of the whole ICT and service infrastructure	• Some of the stakeholder organizations grow tired of development projects • Shrinking of the number of parties in the consortium • Lack of competence of junior researchers • Decreasing creativity and/or the ability to spawn innovations • Not enough ability to increase cost-effectiveness and added value for user organizations • Lack of balance between social and business interests • Lack of achieving a market-ready VT system

Figure 13. This SWOT analysis diagram provides one assessment of the individual and organizational user-centered product development process for the VT via the PERDA.

tend to remain at the level of laboratory prototypes or small-scale field demonstrators, for example the ones aimed primarily at residential use. Therefore, more synergic efforts should be focused on the ability to start large-scale trials, and to find out which ideas are most feasible in regard to the potential benefits for older people and society. It should also be borne in mind that some of the research innovations in technology have been integrated into real-life applications in embedded or diffused ways, such as hidden in subassemblies rather than as separate products, as they were during our R&D projects.

Still, we can conclude that concrete benefits have surfaced from the PERDA. In particular, users are keen on participating in R&D processes, UIs can be radically improved, and the implementation of VT technology into organizations and daily life takes more time than anticipated by R&D personnel and technology companies.

When viewed strictly as academic projects, we believe our PERDA processes with the diversity of cases have been successful. Nevertheless, room for improvement certainly exists. Ways of enhancing the practical possibilities of our PERDA system could include the following four lessons:

- more emphasis on idea generation and the cross-checking of needs versus technological possibilities before building a consortium (cf., Ulrich & Eppinger, 2004);

- macro-ergonomics (Hendrick & Kleiner, 2002) might give a new boost to the general level, and contextual design (Beyer & Holtzblatt, 1999) at a specific level, to achieve a closer contact with stakeholders in field conditions;
- more emphasis on the role of top management in involving companies in the consortia. Although the experts within companies see the important value of product usability (Väyrynen et al., 2002), top management often prefers the attitude of "wait and see" for market demands; and
- allow time (perhaps 4 to 5 years) for the effects of new strategic lines in innovation processes to come to fruition (Kaplan & Norton, 2004).

Regarding the ideal PDCA cycle of development (Hutchison, 1997), we found that in most of our PERDA cases only the Plan and Do aspects could be carried out. Some cases implemented the Check step, but the Act element was lacking almost completely. As far as PERDA is concerned, the most practical developments dealt generally with the PDCA cycle in that it always started by designing (Plan), followed by the phases (Do) in the laboratory or by small-scale field trials; the Act phase on a large scale could not be done. So, the fifth lesson we've learned for future R&D is that the full PDCA process must be used when aiming for a practical new innovation in real life.

The sixth lesson learned concerns dealing with the design process and project reviews (International Organization for Standardization [ISO], 2002) by the management of PERDA consortium participants: More validation efforts have to be made, not only verification, and the review phase of R&D should be carried out quite carefully. *Verification* refers to comparing the design output with the design input, whereas *validation* refers to a comparing of the product/service with the users' needs (ISO, 2002). Quality management (Logothetis, 1992) practices and standards (ISO, 2002) emphasize verification and validation as parts of a successful R&D process.

The seventh lesson is linked to innovations and markets. Kaplan and Norton (2004), for example, conclude that sustaining a competitive advantage requires organizations to continually innovate to create new products, services, and processes. Successful innovation drives customer acquisition and growth, margin enhancement, and customer loyalty. Accordingly, managing innovation includes four important processes:

(a) identifying opportunities for new products and services
(b) managing the research and development portfolio
(c) designing and developing the new products and services
(d) bringing the new products and services to market.

The PERDA and the consortia could take care of the first three processes fairly well, but the fourth one was a clear problem.

As the next step, our own experiences encourage us to emphasize the following points as far as our 3 + 3 model within PERDA is concerned (cf., Figure. 2):

1. For stating requirements
    - Make a thorough user study, particularly getting acquainted with the literature and other more practical documents; and meet directly with the target users in assessing the tasks, context, and conditions, particularly concentrating on the user profile, needs, and wishes.

- Identify the key issues of the future marketing and implementation phases in a given product's life-span.
- Emphasize the quality of the requirements specification (goal setting), and collect or utilize guidelines and so-called "main headings," that is, a list of principal requirement areas (Pahl & Beitz, 1988) regarding the older users' characteristics, needs, and preferences.
- Build a multicriteria model of requirements (Kirvesoja, 2001; Väyrynen et al., 1999/2000).

2. For generating alternatives
   - Utilize multidisciplinary groups of experts and consult both a variety of professionals related to the product idea and the older users directly.
   - Communicate new concepts creatively and in a participatory manner to iteratively customize the concepts according to ideas and feedback.
3. For testing alternatives
   - Remember the best guidelines for heuristic inspection of usability.
   - Compare alternatives by using, for instance, a multicriteria requirements model (see Table 1).

GENERAL DISCUSSION AND CONCLUSIONS

Based on our experiences over the past decade, and highlighted in the two cases presented in this paper, we can conclude that it might be more appropriate to focus on tailoring products (e.g., through customized UI characteristics perceived as desired usability attributes) for older users rather than on customized technology in general (Väyrynen, 2002). It seems to us that often what is needed is not a totally new technology but rather gerontailoring for geronusability of current products. This involves the customization of current products for older users or utilizing the knowledge and/or test results to help older customers make better choices.

Our research underscores that we should emphasize the following features even more:

- The designers should be viewed as partners of the user or the user organization (Majchrzak et al., 1987).
- Designers should know and utilize a larger variety of experimental approaches.
- All participants representing various stakeholder groups should enhance mutual communication, for example, the concept communication (Ulrich & Eppinger, 2004), as we did in our product creation process (Mikkonen et al., 2002).
- Individual and organizational users should be linked to the design process early and through long-lasting actions to promote the implementation of the products (Eason, 1998; Kirvesoja, Oikarinen et al., 1999; Wilson, 1995).
- The outward appearance of the products or technologies under development need to be appealing to older adults (Alakärppä, 2002; Alakärppä & Kovanen, 2002).
- The entire design community should adopt the five key features of design for usability (Shackel, 1986): (a) user-centered, (b) participative, (c) experimental, (d) iterative, and (e) user-supportive. These features are also beneficial for successful implementation.

Recently the design processes have become easier to manage by the R&D personnel because the newest European and international design standards quite rightly emphasize both individual and organizational user-centered design aspects (see European Committee for Standardization [CEN], 1995, 2000; CEN & ISO, 2003a, 2003b, 2004; International Electrotechnical Commission [IEC], 2004; ISO 1998, 1999; ISO & IEC, 2001).

In addition, one possibility for modeling user-centered design is to integrate it under the holistic umbrella of quality. A standard jointly published by the ISO and IEC (2001) deals with a concept of quality in use, including attributes such as effectiveness, productivity, safety, and satisfaction with software products. Contemporary textbooks on ergonomics clearly see the importance of design standards, product and system development, usability, and the implementation phase (Bridger, 2003; Dul, deVries, Verschoof, Eveleens, & Feitzer, 2004). Since Shackel (1986) linked usability and ergonomics, the development of user-centered design has taken giant leaps. Contemporary ergonomics has proven to be an important discipline and practice, particularly regarding successful technological development and change for older users. Both top-down and bottom-up approaches (Deschamps & Nayak, 1995) should be utilized, the former being linked more to organizational participation and the latter to end user participation. Both approaches are emphasized in PERDA.

The question about the appearance of the technologies is essential from the user's point of view, and in particular how those using the technologies will be assessed through the eyes of others. The user of these devices should be perceived as a full, equal member of the community at large, and all products that compensate for disability should be seen as unexceptional products. These specialized products should be seen simply as other consumer products, such as glasses, clothes, and household electronics, which are affected by fashion.

To sum up, products are at their best when they are able to provide added value for all three stakeholders: the manufacturing enterprises; the utilizing organizations, such as the state, municipality, or country, or the service-providing company; and last, but not least, the individual people as workers, citizens, and customers (a win-win-win situation).

The increasing goal of wellness in industrialized societies creates the needs—and provides the resources—for new, tailored products and other technological solutions for older people to help them manage better at home (and at work). To meet these demands, an obvious must is to promote a special user-centered and participatory design to effectively utilize technological progress as a contributory factor to welfare and empowerment. Emphasis on ergonomics and human factors has been shown to be a solution to the challenges of developing or tailoring useful and user-friendly technologies. This emphasis has, according to our experiences, been linked with a decision to set up a cluster of stakeholders to back up R&D projects. In particular, we recommend that a systematic approach of knowing, respecting, and involving older users should be applied. One applicable model is our ergonomic PERDA, with an emphasis on experimental usability engineering within the context of ICT engineering and industrial design.

Obviously our consortia have been quite good at engineering and ergonomics, but for many reasons we have had problems with the commercialization of the products tested. Quality expert Juran (1995) lists several activities that a technology company must conduct to in order to build volume production. Of Juran's recommendations, our group is lacking, for example, "examination of market and economic feasibility" (p. 230). Pahl and Beitz (1988) recommend that designers have close contacts with their sales department.

VT can bring added value to work and life. For example, people can see things and other people remotely, and not only at stationary terminals but also with mobile devices. However, "market trials, especially those in which VT is used in residential settings, are necessary to better understand how it will be used. Although VT will initially be deployed for and applied to interpersonal communication, it will probably soon be used for video information and entertainment services, ranging from catalog shopping to adult-oriented services" (Kraut & Fish, 1997, p. 559). We in northern Finland will continue in the R&D of VT technologies within the PERDA, perhaps utilizing even more multidisciplinary research groups, empiricism, and, especially, enhanced business connections.

For people in the Nordic region—like for many other people living in sparsely populated areas—ICT applications like VT are of special importance. In general, as far as supporting general development in European and corresponding societies, VT is a system able to boost the creation of innovative service markets. Convergence and compatibility of various technologies and fixed or mobile networks offer more and more possibilities for VT to penetrate the public use and the social benefit. At the same time, the knowledge and skills of user-centered design need to be continuously developed.

ENDNOTES

1. Sanders & McCormick (1998) describe compatibility and time-sharing as follows: "The concept of compatibility implies a process of information transformation, or recoding. It is postulated that the greater the degree of compatibility, the less recoding must be done to process the information" (p. 58), and "When people are required to do more than one task at the same time, performance on at least one of the tasks often declines. This type of situation is also referred to as time-sharing" (p. 72).

2. Attributes a and h are related to the organization/other people (Kirvesoja, Oikarinen, et al., 1999; Majchrzak, Chang, Barfield, Eberts, & Salvendy, 1987) in addition to being related to individual users, while all other attributes relate only to an individual user.

3. In attribute b, *effective* refers to the number of tasks and work that can be done (outer productivity), while *efficient* means that a person is able to take care of his/her role when using a product for tasks easily and healthily enough, and without becoming overloaded or outspending his/her resources (see International Organization for Standardization [ISO], 1998).

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COMPUTER VISION INTERACTION FOR PEOPLE WITH SEVERE MOVEMENT RESTRICTIONS

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Abstract: *In this paper we present the starting point of research in applying human-computer interaction (HCI) techniques to help people with cerebral palsy to use computers via vision-based interaction. Our work includes the development and improvement of vision-based assistive technology, which was tested in experiments with cerebral palsy users. A brief review of current assistive technologies for severely physically impaired people and an explanation of the developed applications of such technologies are also presented. The final part of the paper describes the experimentation goals, process, and preliminary results. Future work directions are also indicated.*

Keywords: *accessibility, cerebral palsy, physically disabled users, computer vision interaction, human-computer interaction, design for all.*

INTRODUCTION

This paper explains a research project applying human-computer interaction (HCI) knowledge and techniques, such as accessibility and usability, to help people with cerebral palsy or other severe disabilities carry out specific tasks with a computer. As a first step, our main interest is focused on testing and developing new input devices based on computer vision, and testing different interaction methods. The fundamental goal is to enable users with special needs to access computers easily, or, at least, use the computer as an educational or training tool.

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We have chosen computer vision techniques because they allow for the building of noninvasive, versatile, and flexible systems at a very low cost due the software nature of these systems. The cost of a system, an important aspect of the design process, is too often forgotten. These systems open new paradigms in HCI and allow us to innovate ways of interaction that can benefit people with severe disabilities.

Three bodies are involved in this work: (a) the research community, represented by Grup de Recerca Interacció Persona Ordinador i Bases de Dades (the HCI research group from University of Lleida, Spain; GRIHO, n.d.); (b) the final users, surfaced through the nonprofit Asociación Provincial de Parálisis Cerebral (APPC; Provincial Cerebral Palsy Association, 2006); and (c) the computer vision industry, represented by CREA Sistemes Informàtics (CREA, 2005). The first body contributes through research, the second through actual testing, and the third with product development.

What is Cerebral Palsy (CP)?

According with the United Cerebral Palsy (UCP),

> Cerebral palsy describes a group of disorders of the development of movement and posture causing activity limitation that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception and/or behavior, and/or by a seizure disorder. (Bax, Goldstein, Rosenbaum, Leviton, & Paneth, 2005, p. 574)

Said more succinctly, CP is a nondegenerative disease that has an impact on a user's mobility and, usually, cognitive abilities. This produces a great range of disorders, from slight to severe, where mobility, the senses, language, reasoning, attention, and so forth, are greatly altered. Moreover, the normal development process of the individual is impacted due to motor impairments from a very early age. Therefore, early attention and a specialized education program are necessary to provide the best possible quality of life and autonomy for individuals with CP.

Human-Computer Interaction

HCI is "a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" (Hewett et al., 2004, Chapter 2.1, p. 5).

The discipline studies all the factors related to the communication process between the human and the interactive system with the objective of developing or improving the safety, utility, effectiveness, and usability of interactive computer-based products. By consequence, as Figure 1 summarizes, not only the computer has to be studied (as software engineering does) but also the human physical and mental characteristics (also known as human factors) and the context where the interaction is carried out.

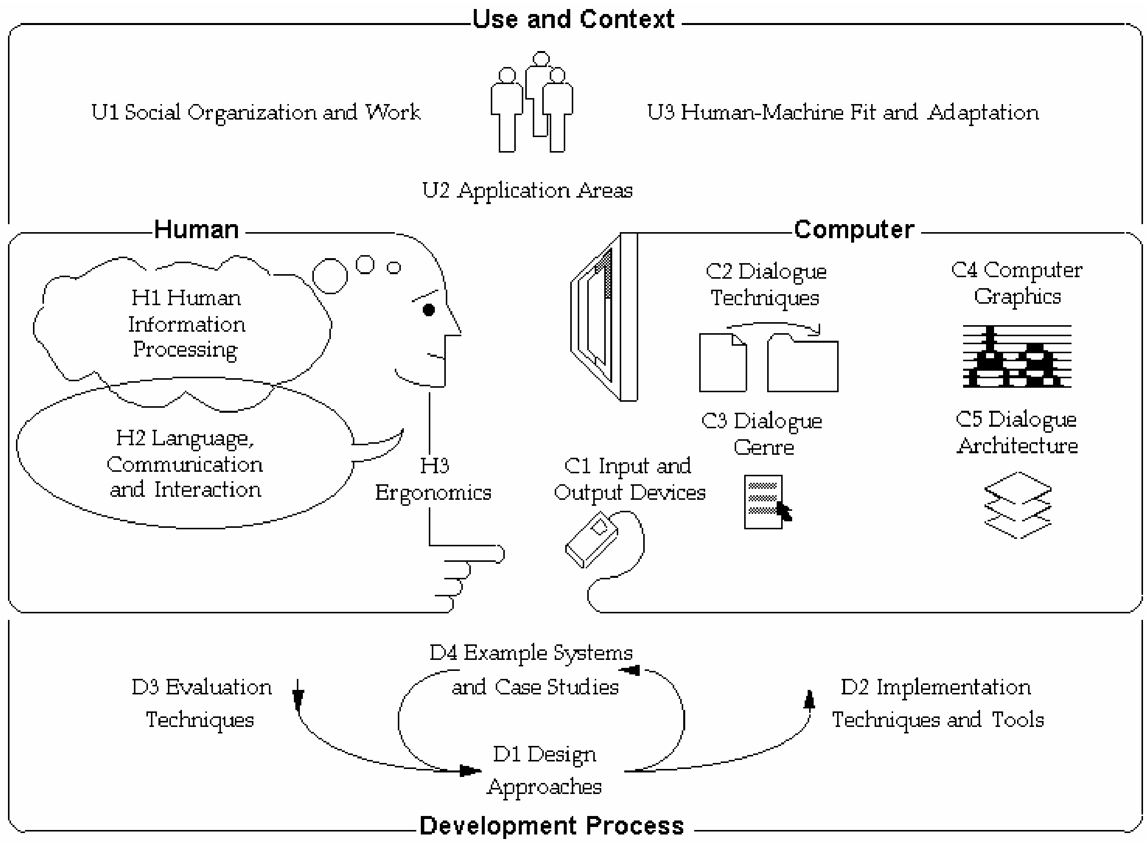

Figure 1. Human-Computer Interaction (Hewett et al., 2004) [1.]

Two of the most relevant HCI attributes are usability and accessibility. *Usability* refers to the extent to which a product can be used by specific users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specific context of use (Usability Net, 2006; see also International Organization for Standardization [ISO], 1998). It is considered within the first-level internal and external software quality attributes (International Organization for Standardization [ISO] & International Electrotechnical Commission [IEC], 2001).

Accessibility means that people with disabilities can perceive, understand, navigate, and interact with an interactive system. Accessibility also addresses the needs of a wider range of users, including people with changing abilities due to aging. Accessibility problems can also be caused by specific environment or social conditions.

Both above-mentioned attributes are largely treated and tested in this paper. First we will explain our work developing technology to overcome accessibility barriers using people with CP as target users. Later, once the interfaces are accessible, our experimentation looked to improve usability of these interfaces.

DESIGN FOR ALL AND ASSISTIVE TECHNOLOGIES

Design for all means that the products and environments should be designed so that they are usable by all people, to the greatest extent possible, without the need for adaptation or specialized design. This will only come about as a result of designing mainstream products and services to be accessible by as broad a range of users as possible (van Dusseldorp, Paul, & Ballon, 1998). An architectural analogy would be the ramp or the elevator (as opposed to the stairs), which makes movement within the environment possible for most people.

Design for all involves the principles of accessibility and usability (see Figure 2). Since accessibility means removing barriers, an accessible system allows a blind person to "view" a Web site or a paralyzed person to move the screen cursor without a mouse. Since usability means minimizing the overload imposed by the use of computers in terms of motor and cognitive load, a usable system makes manipulation of the system easier.

Therefore, design for all also involves assistive technologies to overcome any impairments of a user. In the context of this paper, *assistive technology* refers to the (special) computer hardware and/or software used to increase, maintain, or improve the functional capabilities of individuals with disabilities (Blaise, 2003). Examples of computer assistive technology devices are Braille readers, screen magnification software, eye-tracking devices, and so forth. In spatial accessibly, a wheelchair is an assistive technology device.

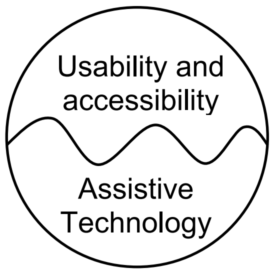

Figure 2. Design for all involves a synergy between usability and accessibility combined with the appropriate user dependant assistive technology.

User Interface Accessibility

From the user's viewpoint, interface means "the whole system." The barriers that disabled and elderly people find when accessing interactive systems are mainly related to the user interface. These barriers reflect the physical difficulties users might have to manage the devices and the cognitive barriers users may have in understanding the operating procedures for interacting with the interface. The studies made with users demonstrate the necessity of adaptable interfaces that allow the control of devices and services through integrated interoperable systems in intelligent surroundings (Abascal, 2003).

Physical Accessibility

Standard interfaces are based on the most common interaction devices: the keyboard and mouse for data input, and the screen (and sometimes speakers) for data output. The use of these devices requires a certain level of physical ability from the user. Input via these devices demands precision and motor coordination; visual-motor coordination is also needed to use the pointing device. Output requires visual and, sometimes, auditory abilities.

People present disabilities in diverse ways. A significant percentage of the general population does not possess the necessary minimum physical ability to use standard input/output devices. This occurs for various reasons, for example, aging, physical or cognitive disability, or the inability to execute multiple tasks simultaneously (browsing the address book of a mobile phone while driving, for example).

Cognitive Accessibility

Interfaces control the user-application dialog through a set of procedures, such as the available commands, browsing procedures, and so on. These elements are related to a model of the task that is explained like a metaphor of the same activity achieved without a computer (for example, dragging a file icon to the trash can). Users must understand the procedures, the metaphors of the browsing process, for instance, in order to successfully complete their task. All of this depends on the vision for operation that both the users and the application have.

The cognitive abilities and disabilities of users are diverse (Cañas & Waern, 2001). Besides aging and cognitive disabilities, the use of a foreign language or the reduction in attention when doing simultaneous tasks may influence the cognitive ability of the user. Therefore it is necessary to take into account this diversity when designing interaction methods. Despite the fact that the cognitive disabilities affect a large number of people, many of whom are not considered disabled, cognitive accessibility studies are less developed than those for physical accessibility.

Computer Assistive Technology Devices

Focusing on the severe physical motor disabilities and interaction at the sensory-motor level, most of the recent computer assistive technology devices are based on the extraction of a stimulus generated by the users, usually through voluntary movement of any part of their body. Here we have compiled a representative set of computer assistive technology devices commonly used with our disabled target users, individuals with CP. The information presented here comes from organizations and projects like the Centro Estatal de Autonomía Personal y Ayudas Técnicas (CEAPAT, n.d.; National Center for Personal Autonomy and Technical Aids of Spain), the European Assistive Technology Information Network (EASTIN, n.d.), and the on-line database of assistive technology maintained by the United Spinal Association (2004).

Switch

The switch is one of the most simple and widely used computer access systems and consists of an electrical device that the user activates with the part of his/her body that has movement (see Figure 3). Available in different sizes and sensibilities, the switch can be activated by the hand, foot, head, or by blowing, for example.

In general, switches allow for a simple interaction and are usually combined with (screen) scan software. The scan is done in one dimension (as a list of menu options, icons in a window, rows and columns of the screen, etc.). The user activates the switch when the desired option is highlighted to execute the selection.

Figure 3. Examples of various switches (activated by the hand, head, and chin).

However, this technology has a technologic problem: its low bandwidth. This feature affects a normal communication between the user and the system; the pair action-reaction is not instantaneous (with action meaning "what the user does" and reaction "the system feedback") and can frustrate the user with a lot of dead time.

Joystick

The joystick is a well-known computer peripheral used mainly for gaming. In the ambit of disabilities it is used for controlling a mouse pointer (see Figure 4) or driving a wheelchair, for example. It usually acts as a substitute for a mouse when the user has difficulties using one. There are joysticks that can be used with the hand, foot, chin, or mouth.

Interaction is based on a succession of directional selections over time; this allows for a greater bandwidth than the switch. But the time constraint remains present when emulating the mouse functionality. Thus the user must wait while the pointer is moving.

Figure 4. Examples of joysticks (hand, chin, and mouth).

Trackball

The trackball is a pointing device consisting of a ball housed in a socket that contains sensors to detect the rotation of the ball around two axes. The user rolls the ball with a thumb, the palm of a hand, or another part of his/her body to move the screen pointer. Trackballs are useful for people with reduced mobility in their upper limbs and where the lack of precise motion invalidates the use of the standard mouse. Interaction is done across two dimensions and equivalent to a mouse.

Keyguard

The keyguard is a rigid plate, usually made of methacrylate, with holes in it that coincide with key positions in the keyboard below. Keyguards are available for standard computer keyboards and for a range of specialist keyboards. They are useful for people with erratic movements and help decrease undesired keystrokes.

Virtual keyboard

The virtual keyboard is an on-screen representation of a (standard) keyboard (see Figure 5). As long as the person can control a mouse, trackball, or other pointing device, he/she can mimic keystrokes for virtually any application.

Figure 5. Screenshot of the virtual keyboard included in the Windows operating system.

Speech Recognition Software

Speech or voluntary sound emission also can be used by people to interact with computers. Core uses include sending simple verbal orders (opening an application, clicking the mouse, etc.) or continuous speech recognition to write text.

Head Pointer

The head pointer is a pointing device controlled with the user's head and is useful for people with good cephalic control. There are different kinds of head pointers.

- Head sticks are head-worn pointers (see Figure 6). These can be used in a number of ways: for signaling pictures, words, communication board icons; as a keyboard aid; or as a pencil holder, for turning pages or drawing, for example. The only requirement is the user ability to move their head with certain precision. The user of these devices heavily depends on third party assistance in order to place the device on user's head.
- Light (laser) head pointers. These have evolved from the early head pointers. A laser emitter is mounted on a head-worn device and can be used for signaling functions. The main difference from the preceding technology is that while the older pointers interact with physical touch, the new ones interact with a laser light.

Figure 6. Examples of head stick pointers.

- Electronic head pointers. Based on infrared (HeadMouse Extreme[2], IRdata 2000[3], SmartNav 3 Hands Free Mouse[4], Tracker One[5]) or ultrasonic technology (HeadMaster Plus[6]), these devices usually require a mounted headset or reflective dot on the user's head to make the system functional. The pointer is used mainly to control an onscreen pointer.
- Webcam-based devices. These devices usually track facial features to gather the user's motion and do not need any headset or dots mounted on the user's head. As a result, third party assistance is minimal. Moreover, Webcam-based head pointers are usually software-only solutions based on standard hardware, thus they are cheaper than electronic ones. (See Betke, Gips & Fleming, 2002; HandiEye[7], Hologram[8], Mauri, 2004; QualiEye[9]).

All head pointing devices usually emulate a standard mouse, meaning they have a two-dimensional interaction space equivalent to a standard mouse. The click generation is usually done through the mouse-over method (also called a dwell click; Bohan & Chaparro, 1998) that consists of stopping the pointer over the desired location for a moment.

Eye Tracking

An eye tracking system consists of one or more cameras that focus on one or both eyes and record the movement as the user looks at an area. Eye tracking setups vary greatly: some are head-mounted, some require the head to be stable, and some automatically track the head.

Eye tracking in HCI is used frequently for usability analysis purposes or as a method of input in gaze-based interfaces. The latter is what interests us because such systems allow the use of a computer by people with eye-only motion. (For an overview of eye tracking applications, see Duchowski, 2002.)

Neural Interfaces

Neural interfaces allow computers to pick up the user's intention through sensors connected to nerve terminations on different parts of the body or directly to the brain. Because interaction is done solely through the voluntary control of user's own mental activity[10] this technology implies that no mobility is necessary for use.

COMPUTER VISION-BASED INTERACTION SYSTEMS

Computer vision-based interaction systems process the images coming from one or more cameras to extract features that are interpreted for implementation by way of specialized software. These systems are extremely flexible because any modification detected in the video is susceptible to be interpreted by the computer and used to unleash some action.

There are many advantages to computer vision-based interaction systems. First, a user can interact at a distance, without physical contact with the device. Additionally, virtually any part of the body with mobility can be used to perform the interaction, which is especially important for people with severe physical disabilities. It is also possible to combine classic interaction peripherals, like keyboard or mouse, to improve interaction in a multimodal way. In addition, Webcam-based technologies, for instance, are particularly affordable compared to professional (industrial) computer vision devices.

The idea of using computer vision-based interaction systems for people with severe movement restrictions is not new. As stated above, several systems exist in the market. However, these systems are mainly oriented toward face tracking. Furthermore, these systems are usually not useful for people with seizure disorders like spastic movements (Gips, Betke, & Fleming, 2000).

In this paper we present two new types of computer vision-based systems: one based on face tracking and the other on color tracking. These systems overcome the limitations of the former systems for people with spastic movements and seizure disorders. This paper includes information on the research and development of these two systems: the Facial Mouse and the WebColor Detector (García & Mauri, 2004, 2005).

Facial Mouse

The Facial Mouse[11] is a mouse emulator system based on the facial movement of the user. A Webcam is placed in front of the user, focusing on the user's face. A motion extraction algorithm, which is user independent, is used to extract the facial motion from the video. This motion is used to move the mouse pointer that is controlled in a fashion relatively similar to standard mouse devices. This system can be used with great accuracy even when the user has exiguous cephalic motion control.

The click can be generated through several mechanisms:

- Built-in mechanisms.
    - Dwell click. This click is automatically generated after stopping the pointer for a certain amount of time.
    - Sound click. The click is generated when the user emits a sound whose input level is greater than a configured threshold.
- External mechanisms. An external device can be used to send click commands to the computer, like a keyboard, a standard mouse or a mechanical switch for example.

The Facial Mouse's working environment is composed of a camera, a computer, and the software (see Figure 7). Three elements are presented on the computer screen for the user:

- Application's main window. This shows the live video and offers all menu options.

- Click bar. This is the main complement for click selection and execution. It consists of a toolbar docked at the top of the screen (click bar) that allows for choosing the appropriate mouse action (right/left click, drag & drop, and double click).
- Task bar icon. This utility is used to maximize or minimize the application's main window.

Figure 7. The Facial Mouse's working environment. The Webcam captures the user's movements that a software program translates in order to position the cursor on the screen.

The WebColor Detector

This software, which uses a camera to gather data, is able to detect in real-time the presence or absence of a distinctive color and to track its position. WebColor also includes a built-in human skin color model.

Currently, WebColor emulates the functions of a switch, a joystick (to control the mouse pointer), and a mouse. Color markers are usually fluorescent-colored pieces of paper (see Figure 8) that can be attached to any surface or to the user's body.

Figure 8. Fluorescent color marker samples.

Working Environment and Basic Operation

Figure 9 shows a sequence of the internal WebColor operation. The first step must train the software for the desired color, which is then saved and reused in subsequent executions. The training is performed by making a single click over the desired color.

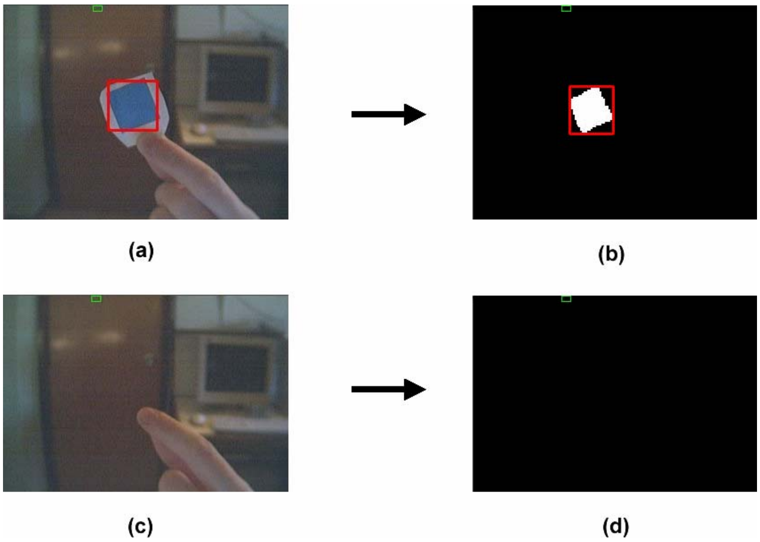

Figure 9. (a) After the color training process, WebColor detects a blue color, and then a red box encircles the marker. (b) The program "sees" only the white stain that corresponds to the marker, a red box encircles the marker; (c) When the mark is removed, (d) the result is a black image because nothing is detected.

Afterward, the application automatically finds and tracks that specific color marker as a means of operating the system. The working environment of the program, then, allows for the related applications of the switch, the joystick, and the mouse to be activated. These modes of operation are explained more fully below.

Switch Emulation

The switch functionality is the most simple. The marker can be attached over a surface, like a table or wall (static marker), or over the user (dynamic marker). When using the static marker the user must cover or uncover the marker by moving the part of the body that has mobility. When using the dynamic marker, the user must move the part of his/her body that has the marker attached (and has mobility, of course) until it appears or disappears in the video. When the marker appears or disappears (this behavior is configurable), an action is triggered. The action can be configured as a mouse click or keyboard keystroke. Usually this system is used in conjunction with third-party interactive switch-oriented software.

Mouse Emulation

In this working mode the position of the marker in the video is coordinated with the screen pointer. So moving the marker in the web camera scene moves the pointer on the screen (for dynamic marker users only). The click is emulated with the dwell click technique or the user can select the appropriate action from the click bar at the top of the screen.

Joystick Emulation

This mode also allows control of the mouse pointer, but in this case the user interacts in a joystick mode fashion. In the video window, a 3 x 3 matrix is shown in red (see Figure 10).

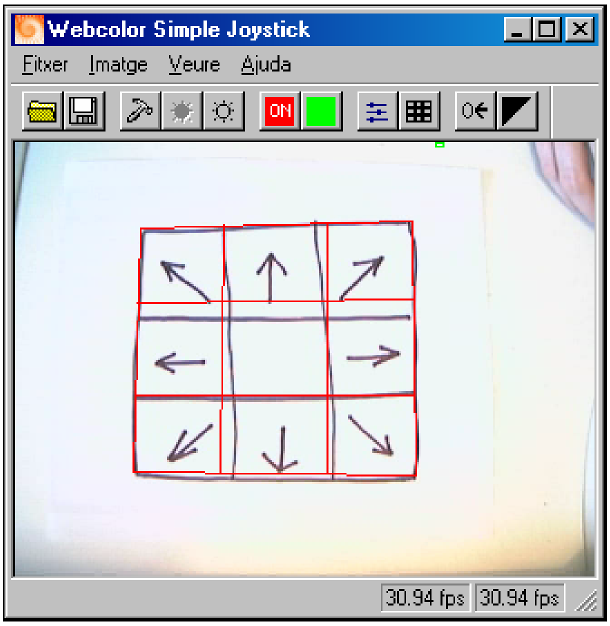

Figure 10. WebColor screenshot running the joystick emulation mode.

Each cell corresponds to one of the eight possible directions and the central cell is used to click. When the marker is in one of the external cells, the pointer begins moving in the appropriate direction, first at low speed then faster as time advances. The click is generated by putting the mark in the central cell and waiting for a specific amount of time (dwell click). The joystick emulator also has a click bar.

Moreover, the joystick matrix is not fixed; it can be adjusted to fit a matrix that the camera sees, for example, the matrix painted on a paper. One useful process we have found for improving the usability for all users has been mounting the camera perpendicular to the table and putting a drawing of a matrix with the eight directions to provide a reference.

A typical session with the WebColor includes the setup of the user, establishing marker location, and positioning the camera, depending on the kind of interaction planned. With the switch, the marker can be attached anywhere; all that matters is that the user is able to show or hide it as stated above. With the mouse and the joystick applications, the marker should be attached to the user where he/she has mobility, usually on the forehead, hand, or finger.

EXPERIMENTS

The two core purposes of the experiments were to validate the usefulness of the systems and to improve the interaction of the devices in actual use conditions. An interdisciplinary team was formed, consisting of a computer science engineer, who served as the research process coordinator and development supervisor, and a special education teacher who was responsible for the user experimentations at the APPC center. In addition, this team had the support and advice from researchers in the areas of speech therapy and physiotherapy.

Technical Setup

All the work was done in the APPC center (located in Tarragona, Spain), where we have a research laboratory equipped with a computer, several Webcams, and the necessary software, including the two systems explained above, and assorted special education software. These resources were provided by the APPC and CREA.

User Selection

For the trials we selected users from the three APPC centers, the La Muntanyeta school, the Gresol occupational workshop, and the Trèvol residence. The selection resulted in 11 persons, 5 women and 6 men, aged from 4 to 35 years.

This selection was done taking into account two parameters: the physical and cognitive conditions of the participants. We chose users with mobility in at least one part of their body and with sufficient cognitive ability to understand and execute simple orders.

Moreover, we developed a database where we compiled information about the selected users, such as name, birth date, medical record, physical and motor challenges, previous computer usage and manner of access, and a preliminary work plan. The database was also used to compile notes taken during experimentation sessions.

Testing Procedure

The experimental methodology was a qualitative evaluation. This evaluation took into account the accessibility and utility improvements introduced by the two new assistive devices (Facial Mouse and WebColor Detector) as compared to the computer experience of the user with previous systems. A simple scale was used to assess the change of in the quality of the interaction (see Table 1). Although a number of different tests were carried out with each of the participants, all of the obtained results were based on the perceived change as evaluated by the special education teacher. Thus, the data reflecting the degree of change were derived from a subjective measure.

Each user participated in several experimentation sessions, ranging from two to eight sessions. The duration of each session was variable, depending on the user's fatigue and attention levels, but the sessions lasted from 15 to 45 minutes. This time included the positioning of the user, cameras, and computer, which normally took about 5 minutes.

The goal of the first session was to familiarize the user with the working environment (screen, camera, color marker, and interaction pattern to execute) and to decide which system, the Facial Mouse or the WebColor, was better suited for each user. Depending on the cognitive level of the user, greater or lesser assistance from the teacher was needed in this step.

Table 1. Accessibility and Utility Improvements.

Qualitative evaluation	Description
No improvement	No improvements were shown.
Slight improvement	Minimal human computer interaction achieved.
Great improvement	Useful human computer interaction achieved.

In the following sessions, we studied the two computer vision applications. According to the cognitive level of each user, two core objectives were pursued: basic computer interaction, based on educational software or utilities developed at the APPC (simple Macromedia Flash applets or PowerPoint presentations), and higher level interaction, based on common computer desktop applications (drawing, writing, Internet browsing, e-mail, etc.). These sessions were useful in evaluating the functionality and compatibility of the selected computer vision application with each user and to compare it with that user's previous computer interaction experiences.

Results and Discussion

During the experiments the Facial Mouse system was shown to be less useful than the WebColor Detector system for the users of the study. Only 2 of the 11 experiment participants were able to use the Facial Mouse properly to control the mouse pointer; other participants used it merely as stimulation tool (erratic head motions were used to move a picture across the screen to attract the user's attention). The Facial Mouse seems to be especially suited for people with difficulties using a standard mouse but who have good cephalic control, which is not common for individuals with CP. The WebColor Detector, on the other hand, showed great flexibility in use by the individuals with CP, especially with the switch emulation.

The ease of use and preparation of the switch emulator in the WebColor Detector were the most noticeable features, compared to the use of mechanical switches that must be mounted in specialized supports. The joystick emulation was very useful for the participants who had enough motor capabilities to move one arm over the table but not to use a standard mouse. However, as a mouse emulator, the WebColor's performance was poor when compared to the Facial Mouse, which is more precise and smooth. Table 2 summarizes the evaluation for each participant.

Table 2. Resulting Evaluation for Each User.

User	Age	Diagnosis	Qualitative evaluation
GRS	34	Spastic tetraparesia	Great improvement with Facial Mouse
CGA	34	Spastic tetraparesia	Great improvement with Facial Mouse
JBG	15	Spastic tetraparesia & low-vision	Slight improvement with Facial Mouse
RCL	17	Spastic-distonic-athetoid tetraparesia	No improvement. Uses a joystick to access the computer.
HR	16	Spastic-distonic-athetoid tetraparesia	No improvement. Uses a joystick to access the computer.
JI	4	Spastic-distonic tetraparesia	Slight improvement with WebColor Switch.
ENG	30	Spastic tetraparesia	Slight improvement with Facial Mouse and WebColor Switch
ADS	35	Mixed tetraparesia	Slight improvement with Facial Mouse
ICG	26	Spastic cerebal palsy	Slight improvement with WebColor Switch
MEM	8	Spastic cerebal palsy	Great improvement with WebColor Mouse.
IAMF	12	Spastic tetraparesia	Slight improvement with WebColor Switch

CONCLUSIONS

Computer vision-based interaction is an emerging technology that is becoming more useful, effective, and affordable. However, it raises new questions from the HCI viewpoint, for example, which environments are most suitable for interaction by users with disabilities. In our case we put emphasis on the accessibility and usability aspects of such interaction devices to meet the special needs of people with disabilities, and specifically people with CP.

Despite the fact that our work has just started, preliminary results show that, in general, computer vision interaction systems are very useful; in some cases, these systems are the only ways by which some people can interact with a computer. Computer vision-based interaction systems also give advantages—such as flexibility and lower cost—over other traditional assistive technologies.

The switch and joystick emulators of the WebColor Detector system have been very effective for users with CP. Overall, the WebColor Detector proved more applicable to the CP field. On the other hand, the program's mouse emulator showed a poorer performance than the Facial Mouse system. In those cases where the Facial Mouse could be used by persons with CP, it provided richer interaction with the software than did the WebColor system.

The results obtained with the participants with CP may be easily exportable to other people impaired by phenotypically similar disorders. For example, the Facial Mouse is being used by spinal cord injured quadriplegic people (Hospital Nacional de Parapléjicos [National Hospital of Paraplegics], 2004).

Future work may include the development of multimodal interfaces that combine various computer vision devices with other input devices (Ovita, 2001); improvements in the existing systems to accommodate more the special needs of individuals; the use and development of qualitative metrics with the aim of comparing the effectiveness of various devices and to study users' progress across time (Jacob, 1990; Noirhomme-Fraiture, Charriere, Vanderdonckt, & Bernard, 1993); the application of computer vision input for stimulation and telehealth (Lewis-Brooks & Petersson, 2005); and the development of alternative strategies to emulate mouse clicks besides the dwell clicks (Jacob, 1990). Finally, we plan to design new experimental environments in order to be able to analyze the whole behavior of the users that are involved in the project.

ENDNOTES

1. © 1992 Association for Computing Machinery, Figure 1 (Hewett et al., 2004). Reprinted by permission.
2. HeadMouse Extreme. http://www.orin.com/access/headmouse
3. IRdata. http://www.irdata.com/irdata2000_en.htm
4. SmartNav 3 Hands Free Mouse. http://www.novitatech.org.au/product.asp?p=247&id=1741
5. Tracker One. http://www.madentec.com/products/comaccess/trackone/about-t1.html
6. HeadMaster Plus. http://store.prentrom.com/cgi-bin/store/HM-3P.html
7. HandiEye. http://www.mousevision.com/assistech/html/products/handieye_pro.htm
8. Hologram. http://www.motionparallax.com
9. QualiEye. http://www.qualilife.com/products/index.cfm?id=183&prodType=0&prodTarget=0
10. In relation to physical and cognitive accessibility, we want to cite the research that Spanish scientist José del Rocío Millán is leading at the Insitute Dalle Molle d'Intelligence Artificielle Perceptive. Dr. Millán's research, called the Adaptive Brain Interfaces (ABI; Millán, 2003), has the main goal of users being able to send orders to a computer through their cerebral waves. Although these technologies are a long time from being a

quotidian reality, undoubtedly people with severe physical impairments would be the first and and perhaps most immense beneficiaries. Applications range from improving communication (virtual keyboards for typewriting or Internet browsing) to environmental control (lights, doors, etc.) to wheelchair motion control.

11. A free demo version of Facial Mouse is available for downloading at http://www.facialmouse.com

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ASSISTIVE TECHNOLOGY AND AFFECTIVE MEDIATION

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Abstract: *The lack of attention towards affective communication in assistive technology and disability research can be potentially overcome thanks to the development of affective computing and affective mediation areas. This document describes the main impairments and disorders that may involve affective communication deficits. We also present several affective mediation technologies that are being applied or may be integrated in assistive technologies in order to improve affective communication for a range of disabilities. Finally, we describe our experience with Gestele, an application that incorporates multimodal elements of affective mediation for people with mobility impairments, as well as the results of an empirical study conducted to evaluate the application's validity in communication via telephone.*

Keywords: *people with special needs, assistive technology, affective communication deficits, affective mediation.*

INTRODUCTION

The abundance of research in the assistive technology area is making it possible for people with special needs, mainly disabled people, to communicate, work, and perform daily activities that they were not able to perform efficiently and autonomously before the existence of these technological aids. Within assistive technology, the Augmentative and Alternative Communication (AAC) research field is used to describe additional ways of helping people who find it hard to communicate by speech or writing. AAC helps them to communicate more easily (International Society for Augmentative and Alternative Communication [ISAAC], n.d.).

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AAC includes many different methods. Signing and gestures that do not need any extra devices are called unaided systems. Other methods use picture charts, books, and special computers. These are called aided systems. AAC can help people understand what is said to them as well as help them to say and write what they want (ISAAC, n.d.). However, in the specific area of communication, there is an aspect that has received little attention from assistive technology researchers: affective communication.

Human beings are eminently emotional, as their social interaction is based on the ability to communicate their emotions and to perceive the emotional states of others (Casacuberta, 2001). However, a wide range of disabilities involve deficits in the different stages of affective processing (sensing, expressing, or interpreting affect-relevant signals). Consequently, people with these kinds of disabilities can be considered emotionally handicapped (Gershenfeld, 2000). *Affective computing*, a discipline that develops devices for detecting and responding to users' emotions, and *affective mediation*, computer-based technology that enables the communication between two or more people displaying their emotional states (Garay, Abascal, & Gardeazabal, 2002; Picard, 1997), are growing research areas (Tao & Tan, 2005) that must join assistive technology research to improve the neglected area of affective communication in disabled people.

The Laboratory of Human-Computer Interaction for Special Needs (LHCISN) research group at the University of Basque Country, Spain, is currently devoting efforts to such an aim. These efforts are materialized in the *Gestele* prototype*,* a multimodal and multistage affective mediation system for people with mobility and speech impairments (Garay-Vitoria, Abascal, & Gardeazabal, 2001). In the following pages, we present the definition of assistive and affective mediation technologies. Second, we describe the main affective impairments or disorders that create communication difficulties. Third, we present a review of the effort devoted to improving affective communication in both the assistive technology and the affective computing areas. Finally, we focus on the description of the Gestele system and an empirical study conducted to validate its affective communication.

ASSISTIVE TECHNOLOGY

Assistive technology is defined by King's Fund Consultation as "any product or service designed to enable independence for disabled and elderly people" (Foundation for Assistive Technology, n.d.,¶1). This technology is making great progress due to several reasons, such as technological advances, legislation, research and development programs (both within Spain and internationally), the proliferation and relevance of users' associations, and so forth. This field includes knowledge from sources such as computer science, telematics, and robotics, and, more specifically, fields such as human-computer interaction (HCI), domotics, artificial intelligence, multimedia technology, ergonomics, to name a few. Assistive technology has to cope with a variety of problems, such as detecting users' needs, evaluating results, social and ethical issues, the issue of affordability, and the use of a technology appropriately related to the problems at hand. It is interesting to note that the process of making devices accessible to people with special needs frequently causes such devices to become more accessible for the entire population (Vanderheiden, 1998).

Assistive technology research has made great advances in the area of the verbal, or explicit, communication channel. The LHCISN especially has made a notable effort in the development of *communicators*, that is to say, machines (with their corresponding software) that allow users with motor and oral disabilities to communicate (Garay-Vitoria, 2001; Gardeazabal, 2000). Communication usually takes place through the generation of messages in various forms to be received by the interlocutors. This technology usually serves to write messages that can be seen on a screen device, be printed, or be synthesized via a text-to-speech system. The major areas of research are presented here.

Reduced Keyboards

A keyboard is called a reduced keyboard when the number of keys, "k," is fewer than the number of selectable characters, "c," which is the cardinal number of the selection set (Gardeazabal, 2000). These keyboards prove to be extremely useful, for example, when sending SMS (Short Message Service) communications on mobile phones, as well as helping users with special needs. The usual key distribution is the T9 keyboard[1], however, there are studies that try to obtain better distributions (Arnott & Javed, 1992; Foulds, Soede, & Van Balkom, 1987; Gardeazabal, 2000; Lesher, Moulton, & Higginbotham, 1998a; Levine, Goodenough-Trepagnier, Getschow, & Minneman, 1987). The disambiguation that the reduced keyboards achieve can also be used as a prediction system.

Scanning Set Distribution

In scanning input, the distribution of the selection set is crucial to optimize the time required to compose messages. A number of studies in the literature address this matter (Gardeazabal, 2000; Lesher, Moulton, & Higginbotham, 1998b; Venkatagiri, 1999). For example, Gardeazabal (2000) studied the optimal distribution with bidimensional and tri-dimensional matrices. It was observed that the access time changes when taking item frequencies into account. In two dimensions, square matrices are a valid choice. With more than two dimensions, several distributions that achieve very good results are found, and usability studies have to be carried out in order to determine the best for each particular user.

Automatic Adaptation of the Scanning Period

Scanning-and-selection input systems scan the selection set with a fixed time period "T". Text production is highly influenced by this parameter. Large "T" values produce longer text composition times. Therefore, it is important to maintain "T" values as short as possible. However, it has been observed that too short a "T" value increases the number of mistakes made by the user, and therefore affects the time of message composition. Gardeazabal (2000) presents systems based on fuzzy logic and traditional logic, taking into account factors such as fatigue, error rate, and so on, to smoothly adapt the scanning period to specific users.

Text Prediction

Prediction techniques use contextual information to anticipate what a person is going to write (Garay & Abascal, 1994). If the system is able to guess correctly, the number of keystrokes needed to write a sentence decreases. Apart from enhancing communication speed, the physical effort required to compose messages is reduced. In addition, the prediction software may also fix spelling mistakes, reorder sentences and, in general, enhance the quality of the composed messages (Magnuson, 1995; Zordell, 1990). Prediction systems can be seen as intelligent agents that assist users in composing their texts. They capture user inputs to make guesses and provide a list of items as outputs. These outputs can be incorporated into the applications used to compose texts by trying to emulate user behavior. Hence, the most advanced predictors have learning features that are able to make inferences, are adaptable, and act independently. In certain cases, these technologies may converse with users, mainly making personal vocabulary adaptations. These predictors may benefit people with severe motor and oral disabilities, such as cerebral palsy or hemiplegia.

AFFECTIVE MEDIATION

As the brief review in the previous section shows, a great effort has been carried out in order to improve verbal communication. However, the emotional features of verbal communication and the improvement of the implicit, or nonverbal, communication traditionally have received less attention. Therefore, in focusing on the improvement of the affective communication for disabled people, assistive technology research must take the research made in the field of affective mediation into account.

As Figure 1 shows, the main objective of affective computation is to capture and process affective information with the aim of enhancing the communication between the human and the computer. Within affective computing, affective mediation uses a computer-based system as an intermediary among the communication of certain people, reflecting the mood the interlocutors may have (Picard, 1997). Affective mediation tries to minimize the filtering of affective information of communication devices; filtering results from the fact that communication devices are usually devoted to transmission of verbal information and miss nonverbal information. Affective mediation has a direct application within AAC. There are also other applications in this type of mediated communication, for example, textual telecommunication (affective electronic mail, affective chats, etc.). As previously mentioned, applications developed in AAC area are useful for both disabled and nondisabled people.

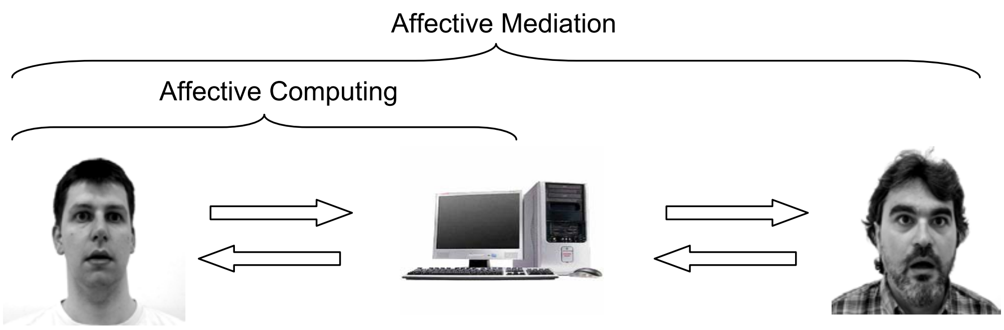

Figure 1. Affective Computing vs. Affective Mediation

IMPAIRMENTS AND DISORDERS INVOLVING AFFECTIVE COMMUNICATION DEFICITS

With the aim of organizing affective computing research, Hudlicka (2003) proposes a classification based on different stages of affect processing, such as sensing, recognizing, interpreting, selecting, and expressing affects. In this document, we use this classification to organize those impairments involving affective communication disabilities. Table 1 shows different types of impairments or disorders signaling the pertinent stage of affective communication.

Table 1. Impairments or Disorders Involving Deficiencies in Affective Processing and the Affective Computing Technologies Useful in Addressing the Deficiencies.

Impairment/Disorder	Impaired stage of affective communication	Useful affective computing technology	Application contexts
Visual impairments (low vision, blindness)	▪ Sensing visual affective information: face and body gestures	▪ Facial affect recognizer ▪ Emotional text readers	▪ Chat or videoconferences
Hearing impairments (pre- & postlocative deafness, etc.)	▪ Sensing speech prosody (pitch, volume or velocity) ▪ Expressing speech prosody	▪ Prosody/speech affect recognizer ▪ Emotional speech synthesizer ▪ Text affective recognizer	▪ Telephone communication ▪ Chat
Learning disorders (e.g., dyslexia)	▪ Interpreting emotions in facial expression (exclusive of a visual perceptual subtype of dyslexia called Irlen syndrome)	▪ Facial affect recognizer ▪ Emotional avatars ▪ Text affect recognizer	▪ Chat ▪ Diagnosis ▪ Training ▪ Biofeedback
Mobility impairments (locked-in syndrome, apraxia, etc.)	▪ Expressing nonverbal information (postural and facial gestures, speech prosody)	▪ Prosody/speech affect recognizer ▪ Emotional speech synthesizer ▪ Sensing devices for psycho- physiological affect recognition (EEG, EKG, skin conductance, eye tracking)	▪ Human-to-human communication ▪ Telephone communication ▪ Proactive/predictive interfaces (Moshkina & Moore, 2001)
Developmental disorders (autism, Asperger syndrome, etc.)	▪ Use of multiple nonverbal behaviors (ocular contact, facial expressions, corporal gestures, etc.) ▪ Recognition of emotions in face and speech	▪ Facial affect recognizer ▪ Emotional Avatars ▪ Prosody/speech affect recognizer ▪ Emotional speech synthesizer ▪ Sensing devices for psycho-physiological affect recognition (EEG, EKG, skin conductance, eye tracking) ▪ Emotional Hearing Aids (Birkby, 2004)	▪ Human-to-human communication ▪ Diagnosis ▪ Training ▪ Treatment ▪ Biofeedback
Anxiety disorders (social or specific phobia)	▪ Affect interpretation and expression: irrational fear to specific stimuli or situations	▪ Sensing devices for biofeedback (EEG, EKG, skin conductance, eye tracking) ▪ Virtual reality	▪ Treatment (systematic desensitization)

Sensing External or Internal Affect-Relevant Signals

Emotional information is transmitted mainly through two channels of human communication: the verbal or explicit channel (language) and the nonverbal or implicit channel (Cowie et al., 2001; Knapp, 1980). Therefore, the affect-relevant signals at the sensing stage, for both individuals and machines, can be verbal (speech or text) and nonverbal (facial expression or voice intonation). Among the impairments that would present problems in this stage of affective processing, we find the category of sensorial deficits, mainly visual and hearing impairments (Jacko, Vitense, & Scott, 2003).

Visual impairments are divided into two general categories: blindness and poor vision. Individuals with blindness have absolutely no sight, or have so little that learning must take place through other senses. Poor vision includes dimness, haziness, extreme far-sightedness or near-sightedness, color blindness, tunnel vision, and so forth. Hearing impairment is defined as a lack or reduction in the ability to hear clearly due to a problem somewhere in the hearing mechanism (Jacko et al., 2003). It is interesting to mention that most deaf people learn a different modality of language, the sign language, which has prosody to express affects like in an oral language. For unmediated communication, it is evident that a blind person cannot sense visual affect-relevant signals such as facial expressions or postural gesture of the interlocutor, while deaf people process neither the explicit emotional message transmitted by the speech nor the voice intonation associated with it.

According to E. T. Hall (1998, p. 53), "although we tend to regard language as the main channel of communication, there is general agreement among experts in semiotics that anywhere from 80 to 90 percent of the information we receive is not only communicated nonverbally but occurs outside our awareness." Meanwhile, Mehrabian (1971) affirms that 7% of a message between two people is verbal, 38% vocal (tone, shades, etc.) and 55% is body language. Therefore, in terms of Mehrabian, unaided visually impaired and deaf people lose 55% and 38%, respectively, of the affective information that people without those sensorial impairments are able to process.

Recognizing an Affective State

Several developmental disorders cause problems with the ability to recognize, to comprehend, the affective states of other people. In this category, we include developmental disorders such as autism or Asperger syndrome, and learning disorders such as the so-called visual dyslexia.

Regarding autism, it is interesting to highlight that one of its diagnostic criteria is the deficit in the use of nonverbal social communicative behaviors (e.g., eye-to-eye gaze, facial expression, or social reciprocity). One noted problem of these individuals is their great deficit in the recognition of faces (Boucher & Lewis, 1992; Klin et al., 1999; Tantam, Monaghan, Nicholson, & Stirling, 1989) and facial expressions, in particular (Capps, Yirmiya, & Sigman, 1992; Celani, Battacchi, & Arcidiacono, 1999; Pelpherey et al., 2002). For instance, Pelpherey et al. (2002) asked a group of autistic and a group of nonautistic adults to identify the emotion portrayed in a set of pictures of facial expressions from the database of Ekman and Friesen (1976). Researchers found the autistic group identified a smaller percentage of the emotions in comparison to the nonautistic group (concretely, fear was the emotion that established the difference). Furthermore, the analysis of the visual scan path revealed that individuals with autism scanned relevant areas of the faces (e.g., eyes, nose, and mouth) less frequently than the control group.

In addition to the facial recognition deficit, autistic individuals can also possess a deficit in emotional prosodic recognition. This fact has been documented (e.g., VanLancker, Cornelius, & Kreiman, 1989) and, at the moment, the use of prosodic information is being considered for both diagnosis and enhancement of emotion recognition in autism disorders (Hall, Szechtman, & Nahmias, 2003). As we will see in the following sections, this data can be taken into account by researchers when designing affective mediation technology for people with autism.

On the other hand, the deficit in facial expressions recognition does not seem to be exclusive to disorders in the autism spectrum. In fact, a kind of dyslexia, named visual dyslexia or Irlen syndrome, also displays deficits in this area. Dyslexia is a learning disorder characterized by difficulties in single word decoding that is not a result of a generalized developmental disability or sensory impairment. Irlen syndrome is claimed to present a deficit in the magnocellullar visual neurological pathway (central nervous system) that would cause visual processing problems. Robinson and Whiting (2003) carried out a study contrasting a group of children with Irlen syndrome with a group of children with no learning disability. The participants performed a facial affect recognition task built with facial affect pictures from the Ekman and Friesen (1976) database. Researchers found that children with Irlen syndrome obtained lower recognition scores than the control group. The authors interpreted the findings as supporting the claims that individuals with Irlen syndrome are more likely to possess social interaction problems due to the deficits in the interpretation of subtle visual clues such as emotional facial expressions. Again, this problematic aspect of affective processing should be taken into account in the design of assistive technology for people with this kind of disorders.

Interpreting and Appraising the Current Situation to Derive, Select, or Generate an Affective State

Developmental disorders, such as autism or Asperger syndrome, or anxiety disorders, such as social or specific phobias, often result in an individual's inability to accurately assess, interpret, or generate an appropriate affective state. As mentioned before, people with autism spectrum disorders show qualitative alterations in their nonverbal communication abilities. Apart from the apparently proven deficit in the recognition of prosody and facial expressions, they possess a deficit in the interpretation of affective signals. For instance, an Asperger individual may recognize a happy facial expression, but not interpret what it means and how to respond to it.

An added problem for people with these kinds of disabilities is that they cannot judge other people's motivations. Hence, such individuals can be victimized by frauds or even worse exploitation. It may be useful to explore whether affect detection technology could help preventing these situations.

On the other hand, anxiety disorders such as social phobia are characterized by irrational fear toward the presence of an object or to a specific situation (spiders, flights, or social situations). Irrational fears can be interpreted as cognitive distortions that are manifested in an exaggerated and irrational emotional response. Affective computing technologies may be applied to assist phobic individuals in the treatment of these handicapping emotional responses.

Expressing the Affective State via One Established Behavioral Script

According to the bio-informational model proposed by Lang (1979, 1984), the emotional response can be produced through three systems: the subjective, or verbal; the behavioral; and the physiological. Impairments or disorders that compromise the correct operation of any of these systems can potentially affect the expression of affective states. In this category, it is possible to mention once again, sensorial impairments such as prelocutive deafness and mobility impairments such as locked-in syndrome or apraxia. People with prelocutive deafness have difficulties achieving functional levels of the oral and written language (e.g., Alegría, 1999; Asensio, 1989; Fajardo, 2005; Leybaert, Alegria, & Morais, 1982; Silvestre & Valero, 1995), so emotional communication through these ways is deficient. Regarding mobility impairments, one of the most relevant examples is the locked-in syndrome, which is characterized by a complete paralysis. In these individuals, verbal self-reporting is difficult and slow because they frequently have to use direct brain-machine interface technologies (Moshkina & Moore, 2001) or predictive keyboards (Gardeazabal, 2000) to communicate. Moreover, due to various reasons (such as problems in the articulation of facial gestures), people with apraxia also possess difficulties in the production of oral language, and consequently in the transmission of the verbal and nonverbal emotional aspects associated with these media (message and prosody). As we will see later, both types of mobility impairments could benefit from an assistive technology that helps expressing affective states.

So far, we have presented a partial list of impairments or disorders that may involve affective communication problems. We have tried to provide an example of the practical relevance of the interaction between affective mediation and assistive technology research areas. Next, we continue with the description of affective mediation technologies that can be used by disabled people.

APPLICATIONS OF AFFECTIVE MEDIATION FOR ASSISTIVE TECHNOLOGY

According to Hudlicka (2003), the challenges of affect in HCI encompass recognizing user affect, adapting to the user's affective state, generating affective behavior by the machine, and modeling the user's affective states or generating affective states within an agent's cognitive architecture. In this section, we present a number of the most relevant techniques to enhance affective communication for disabled people in the areas of affect recognition and generation.

Affect Recognition Technologies

As mentioned earlier, Lang (1979) proposed three systems involved in the expressions of emotions:

- Subjective or verbal information reports on emotions perceived and described by users;
- Behavioral information involves facial and postural expressions, speech paralinguistic parameters, and so forth; and
- Psychophysiological responses are expressed by heart rate, galvanic skin response (GSR), and electroencephalographic (EEC) response.

Consequently, with the aim of sensing and recognizing emotions, a computer must incorporate sensors to receive the emotional output from each of the expressive systems of an individual, and emotional models that allow for interpreting such signals. As Picard (1997) suggests, one of the main aspects of an intelligent computer is its ability to recognize emotions and infer an emotional state by looking at emotional expressions, and the capacity for reasoning a situation. In the same way, a recognizer might be a multimodal system, as it may have the ability to see and hear in order to make out facial expressions, gestures, and voice tone, as well as to recognize emotions from a text typed using a keyboard or spoken by the user. Therefore, the recognizer, apart from analyzing voice tone, gestures, and facial expressions, may also analyze the semantics of the words spoken or written by the user.

Some signals communicate emotions better than others, depending on the emotion, the person who is communicating them (with his/her possible disabilities), and the circumstances generating these emotions. Next, we present affect recognizer technologies that can be useful for various disabled people.

Facial Affect Recognizers

Facial affect recognizers try to obtain emotional information from facial expressions by analyzing the spatial configuration of different parts of the face, mainly the eyes, lips, and nose. It may be useful for those people who cannot process such information due to sensorial or visual difficulties or due to developmental disorders, such as autism or Asperger syndrome.

A facial affect analyzer may be helpful for autistic or Asperger individuals to understand the interlocutor’s emotion because they have problems recognizing facial expressions. Birkby (2004) and Kaliouby and Robinson (2005) propose the Emotional Hearing Aid, which is a wearable device receiving input from a digital camera and uses the input file to interpret the mental and emotional state of the interlocutor and to inform the disabled user. As in the case of autism spectrum disorders, the Emotional Hearing Aid may be a suitable solution to assist children with Irlen syndrome to identify facial affects.

Unlike people with an autism spectrum disorder, the hearing and visual impairments that impact affective communication in some people are due not to a perceptive problem or comprehension problem but to a sensorial one. This is a relevant distinction for the design of affective mediation technology because the consequences are not identical. For example, deaf people, once they know that the interlocutor is sad, can produce the correct response (e.g., to comfort the other person). However, in the case of autism, even if the individuals know their interlocutor’s emotion, they do not know how to react to it. For this reason, several technologies, such as the Emotional Hearing Aid, also incorporate a module that sends a recommended reaction to the user.

In order to identify a particular facial expression, individuals rely on the spatial configuration of the major features of the face, that is, the eyes, nose, and mouth (Diamond & Carey, 1986; Farah, Wilson, Drain, & Tanaka, 1998). Autistic individuals present a different pattern of face scanning, which some authors identify as underlying their face affect recognition deficits (Pelpherey et al., 2002). Therefore, sensing devices, such as the eye tracking devices, may be useful as both diagnostic and biofeedback methods for autistic individuals.

Visual impairment is another potential beneficiary from the facial affect analyzers. Although visually impaired people can use other nonverbal and verbal affective cues during the human-to-human interaction, there are contexts where such other cues are not available and the visual ones must take primary relevance. Chats or videoconferences where the speech prosody may be interfered with or deficient are examples of such situations.

Speech Affect Recognizers

Prosody is a speech feature which, together with the linguistic content, conveys the emotion of the interlocutor. Therefore, the speech affect analyzers use voice parameters such as the pitch, volume, or speed of the speech (prosody elements) to indirectly infer the emotion of the speaker. There are diverse laboratories working on this kind of technology; for instance, the LHCISN is currently developing a prototype of a prosody affect recognizer. More specifically, for this type of disorder, the Oregon Health and Science University (OHSU, Portland, USA) laboratory is working on a project that will use speech and language technologies to improve the diagnosis, evaluation, and treatment of communication disorders, such as autism (OHSU, 2005). In the case of evaluation, that project will use speech technologies to measure the prosodic abilities in children's speech or to create speech stimuli to measure the children's abilities in understanding prosodic cues (this second case is addressed again when we discuss generating technologies).

In contrast to visually impaired, visual dyslexic, or autistic individuals, deaf people seem to have a special ability to process facial expression, mainly because they are better than their hearing peers in recognizing faces (Arnold & Mills, 2001). Deaf people may develop this ability in order to obtain emotional information from faces, since the prosody of speech is out of their scope. The lack of prosodic information would not be a problem in human-to-human communication where there is another source of information (nonverbal), but may be relevant in the use of text-telephones, a technology widely used by deaf people. In such cases, the speech prosody recognizers may prove to be useful for deaf people when trying to understand the affective state of the speaker. Accenture Technology Labs are developing an audio analysis technology for emotion recognition to help call center personnel to recognize the emotion of callers (Petrushin, 2000). Although the Accenture product was not intended for deaf people, it may be easily adapted and used by this kind of user.

One obvious and useful application for speech recognition technology is to provide and enhance human-to-human communication for disabled individuals. For hearing-impaired individuals, the interlocutor's words may be recognized and subsequently produced in the form of corresponding animated sign language, which appears on a display screen (Noyes & Frankish, 1992).

Sensing Devices

These devices are sets of psychophysiological response sensors that measure factors such as skin conductance, heart rate, pupil size, and so on. Applications using sensing devices must be able to relate the psychophysiological signals to the emotional responses of the user. Sensing devices are able to collect data in a continuous way without interrupting the person. The Affective Computing research group at Massachusetts Institute of Technology (MIT) in the USA (see Affective Computing, n.d.) is interested in many different sensing devices useful in recognizing affective signals. This research group has developed a prototype of a physiological detection system (Prototype Physiological Sensing System). This is a light and portable system, and relatively robust regarding changes in the user's position. The prototype is based on a combination of four different sensors: the blood volume pulse (BVP) sensor, the galvanic skin response (GSR) sensor, the electromyogram (EMG) sensor, and the respiration sensor. The output from the prototype is ported to a computer for processing and recognition.

Such recognition technology may be useful for people with mobility impairments, developmental disorders (autism or Asperger), or hearing impairments. For instance, Moshkina and Moore (2001) propose that since locked-in people have continuous life monitoring systems, it would be possible to easily capture psychophysiological responses related to their emotional state. In some cases, where traditional measuring systems are too invasive, a kind of wearable computer exists to collect physiological signals[2]. Lisetti, Nasoz, Lerouge, Ozyer, and Alvarez (2003) are working on mapping these signals to emotional states, and they currently use this application for telehome health care. These kinds of applications may prove to be useful for people who are in need of a continuous assistance.

As in the case of face and speech affect recognizers, psychophysiological technologies can be added to the telephones used by hearing-impaired people. This way, these technologies may obtain from or provide to the interlocutor the emotional information that cannot be extracted or provided by means of other sources (pitch or volume of speech). In the same way, since people with autism are not able to recognize the emotional states of the interlocutor well, sensing devices, facial emotional information, and speech recognizers may serve as artificial recognizers to teach them this skill progressively.

Linguistic Affective Analyzer (LAA)

There are two primary types of LAAs: semantic systems and statistical systems. Whatever the underlying system, the objective of this technology is to abstract the emotional information from the linguistic content of text or speech. The potential users of the LAA would be people with reading or language difficulties, such as prelocutive deaf people and people with autism or dyslexia. Several studies have been performed in order to obtain an affective value for written text (e.g., Bradley & Lang, 1999; Strapparava & Valitutti, 2004). For example, the Affective Norms for English Words (ANEW) provide a set of normative emotional ratings for a large number of words in the English language (Bradley & Lang, 1999). Each word has three associated values that correspond to three emotional dimensions: arousal, valence, and control (according to the bio-informational model proposed by Lang, 1995).

Affect Generating Technologies

Within the category of affect generating technologies, we include all the technologies that display the emotional information transmitted by the user, recognized by any of the previous technologies or automatically generated by the computer. Emotion recognition is often considered as a part of emotion analysis. Synthesis is the opposite of analysis; it is the construction of the emotion. Both recognition and synthesis are able to work on the same system: the recognition can proceed to synthesize or generate several options, asking which one seems to be closer to what is perceived by people. This approach of the recognition is sometimes called "synthesis analysis" (see Affective Computing, n.d.). This section presents some of the most relevant technologies related to affect generation.

Emotional Speech Synthesizer

A speech synthesizer is able to convey the emotional state of the users by means of variations in voice parameters, such as pitch, speed, or volume. This can make the synthesizer provide its messages more satisfactorily. Unfortunately, it is difficult to limit the minimum number of necessary parameters to appropriately generate each basic emotion (just as it is hard to delimit the basic universal emotions). Authors such as Cowie et al. (2001) and Schröder (2003) provide a list of other researchers who suggest their own parameters and basic emotions. Several of the most recent tendencies in voice synthesis are based on the concatenation of previously recorded units. Concatenative synthesis is carried out by joining digitalized phoneme and syllable recordings in a coherent way; these recordings are recorded by a speaker and are stored in a database. Voice synthesizers are often called TTS (text-to-speech), as the voice synthesis is the process of creating speech from text.

Although visually disabled people have a normal development of affective communication abilities, they usually must use assistive technologies, such as screen readers with voice output. This output may be emotionally plain and unpleasant. In these cases, the emotional speech synthesizer could make the use of these devices more satisfactory. The same logic can be applied to the cases of hearing- or motor-impaired people. Those deaf people whose speech is difficult to understand usually make use of TTS technology, for instance, to maintain telephonic conversations (Garay et al., 2002; Garay-Vitoria et al., 2001). Motor-impaired people use speech synthesizers not only in telephone communication contexts, but also during human-to-human communication. For this reason, this technology may be one of the more beneficial for this group.

Affective Avatars

Avatar is a Sanskrit word that means the incarnation of a god on earth, and this term has been adopted into computer science via the gaming and 3-D chat worlds. The avatar is the visual "handle" or the display appearance a person uses to represent herself or himself. Thanks to graphical visualization developed for gaming purposes, emotional information can be displayed visually in an easy and comprehensible way. Avatars are actually more centered in physiological information, but behavioral information can be included as well. Three-dimensional and real-time graphics are used to represent a user's signals, and the goal is to provide unique, innovative, and discrete ways to recover data.

The inclusion of affect elements in avatars is being developed by multiple researchers (e.g., De Rosis, Pelachaud, Poggi, Carofiglio, & De Carolis, 2003; Lisetti et al., 2003), and have in mind several objectives (e.g., telehome health care, teleassistance, entertainment, computer as companion). Persons with almost any type of disorder or impairment potentially can benefit from this technology. Anthropomorphic affective avatars, such as the one proposed by Lisetti et al. (2003), can serve as a virtual tutor that teaches autistic people how to recognize facial expressions. Another application found for these systems was the possibility of adapting to the user's states dynamically, which would be very useful for mobility-impaired people. For example, De Rosis et al. (2003) have developed Greta, a realistic 3-D embodied agent that may be animated in real time and is able to express verbal and nonverbal affective signals (mainly facial expressions).

Emotional Robots

Emotional robots may be used in a teaching context as well as avatars, and can serve as companions for elderly people. For example, the Kismet robot "is capable of generating a continuous range of expressions of various intensities by blending the basis facial postures" (Breazeal, 2003, p. 143). One important point about Kismet is that its efficiency has been tested with real users.

Virtual Reality

Virtual reality can simulate interactive worlds that can be experienced visually in three dimensions and provide feedback in multiple modes (auditory, tactile, etc.). It has been used for the treatment of phobic disorders by "immersing the patient in a synthetic universe in which the anxious stimulus is introduced in an extremely gradual and controlled way" (Roy, 2003, p. 179).

After this review, it is clear that there is a great diversity of affective computing technologies that are being or can be used by people with disabilities. However, one important deficiency of these technologies is that they are usually unimodal and unistage, that is, they usually allow for the assistance in only one stage of the affective processing (e.g., sensing) and in one exclusive modality (e.g., visual). We present our own experience in the field by describing Gestele, a specific assistive technology designed to provide affective communication for oral- and motor-impaired people at diverse stages (modeling and expressing) and modalities (speech and text).

GESTELE: A MULTIMODAL AFFECTIVE MEDIATION TECHNOLOGY

Speech is the most common form of communication among people. According to Alm, Arnott, & Newell (1992), it has been estimated that the achieved speed in a normal conversation is about 150-200 words/minute, mainly in the case of the English language. Yet people with certain oral or mobility impairments are not able to use this effective communication channel. Therefore, Gestele was developed with the aim of assisting people with severe motor and oral communication disabilities. It is a mediation system that includes emotional expressivity hints through voice intonation and preconfigured small talk. The Gestele system is used for telephone communication (see Garay et al., 2002; Garay-Vitoria et al., 2001; Garay-Vitoria, Abascal, & Urigoitia-Bengoa, 1995). Gestele allows for different input options (directly or by scanning, depending on user characteristics) and makes holding telephone conversations involving affective characteristics possible for people with no speaking ability. This may be seen as a TTS system applied to telephone conversations by providing help in text message composition.

A telephone conversation can be modeled with a state-transition automaton, such as the one shown in Figure 2 (Garay-Vitoria et al., 1995). E0 is the state when the phone is not being used. In E3, sentences are precomposed for a future conversation. Prepared messages are classified according to their topic in order to allow the minimum effort possible for their selection. The other states are the typical ones occurring during a telephone conversation. System initial interface is shown in Figure 3.

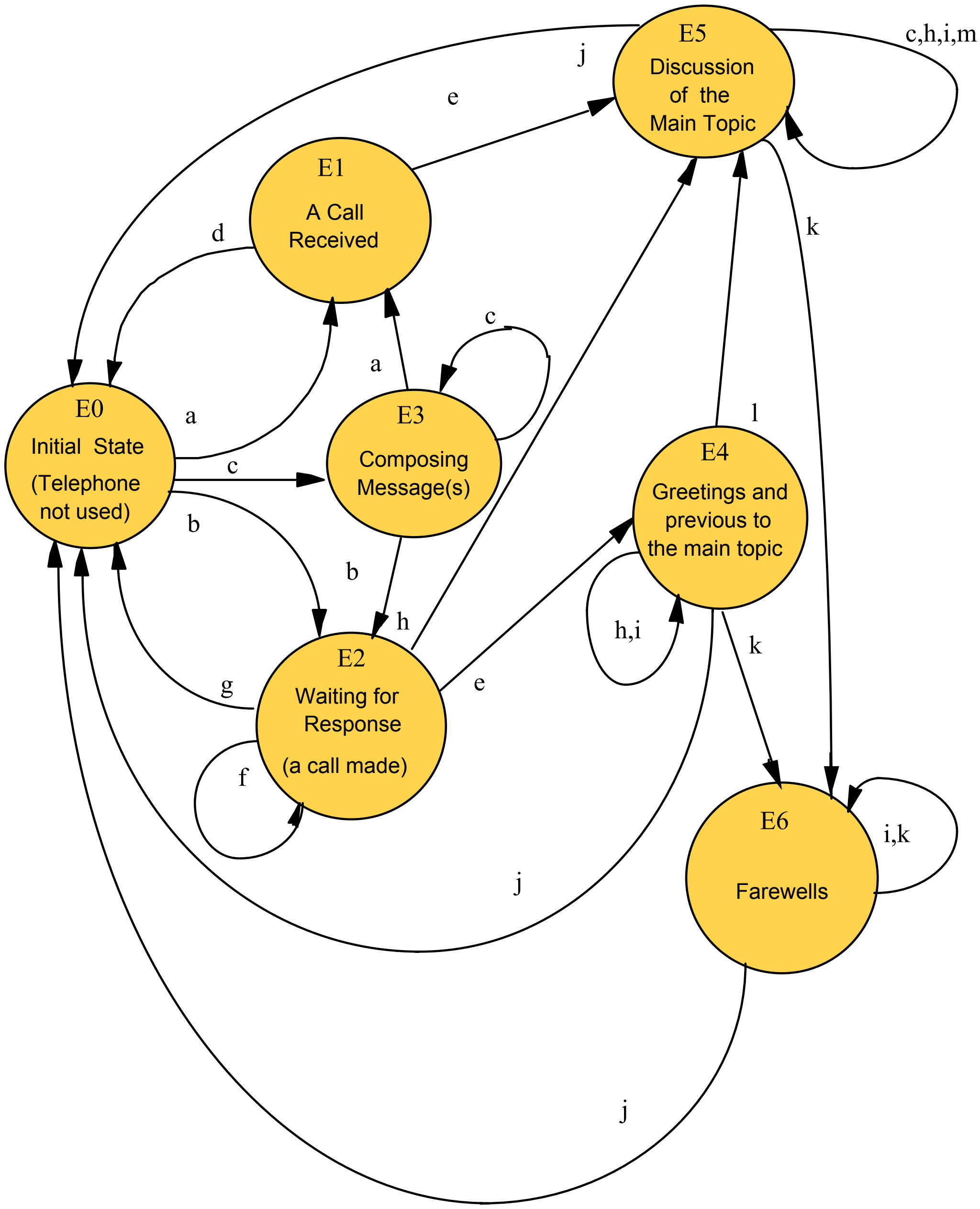

Figure 2. The automaton of the telephonic conversation aid. Notation for the arcs: a) receive a call; b) make a call; c) prepare a message; d) do not answer; e) salute/give a warning; f) asking for confirmation; g) there is no answer; h) send a message; i) send a filler remark; j) hang up the phone; k) say good-bye; l) introduce the main topic; m) give a warning for composing a message.

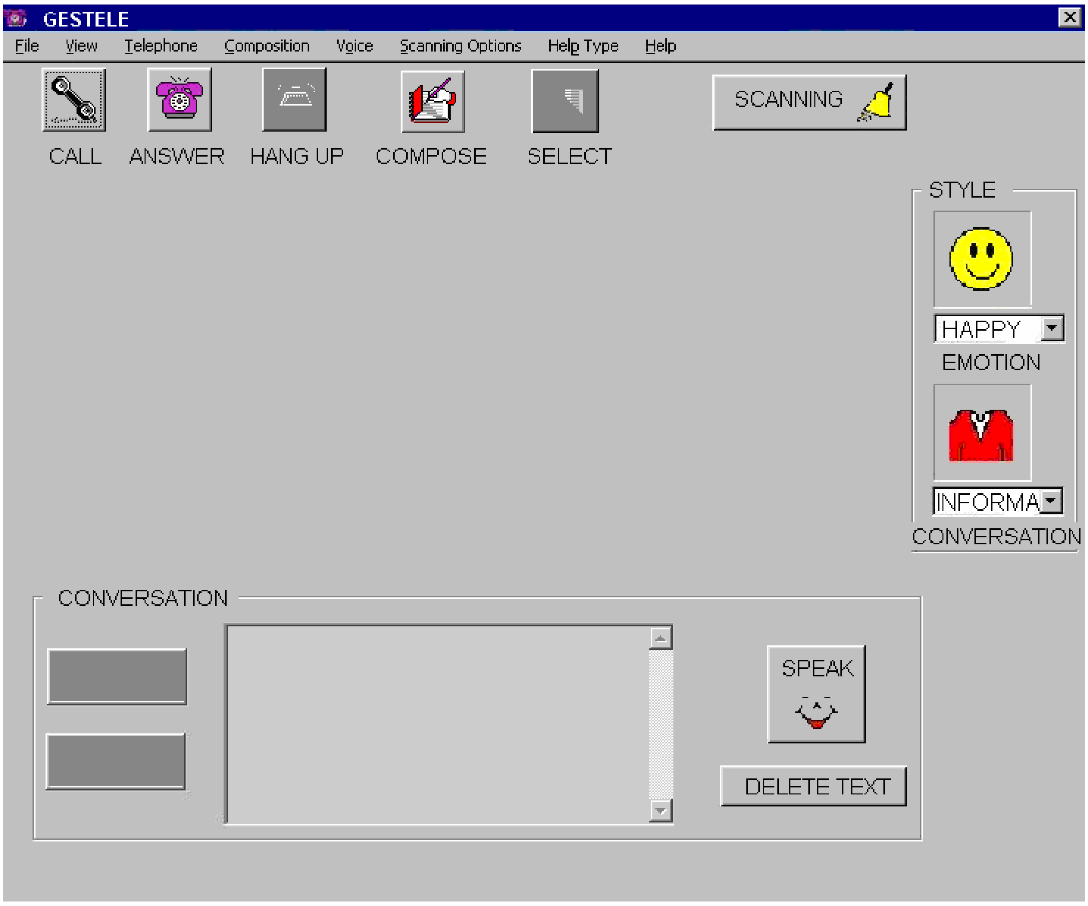

Figure 3. Gestele interface in E0 state of the automaton.

Advancing across this scheme, the user can produce meaningful sentences in the context of the conversation at a reasonable rate and effort. Therefore, in most states of the automaton, the previously mentioned problem of obtaining an acceptable message production speed is solved. When sentences have to be improvised, the user can obtain help from word prediction and composition accelerators, and syntactic and morphologic correctors to type his/her opinions in a reasonable rate of time and with minimal effort.

There are two factors to be kept in mind when building the model of conversation.

1. There is a set of social rules that guides conversational interaction. As conversation is a cultural matter, dialogue modeling is very dependent on the cultural context. Thus, a specific model might not be valid for people living in different countries, speaking different languages, and so on. For instance, the importance and duration of greetings, farewells, and polite questions, to name a few, are very different from one culture to another.
2. The conversation frequently affects the relationships between interlocutors. Consequently, the speaker can appear friendly and intelligent, and can manifest his/her points of view or prejudices. In the mediated dialogue, the interlocutor's personality should appear. If high user acceptation is desired, the model must able to automatically adapt itself to the user's personality.

Gestele allows sentence composition with a scan-based system that may be controlled by a single button. The distribution of the characters in the options matrix has been made by taking the frequencies of the letters in the Spanish language into account, as mentioned in Arruabarrena and González-Abascal (1988). The scanning speed is predefined but it can be changed using the options in the state bar of the interface. The options matrix is shown in the middle left part of the interface (see Figure 4).

To enhance communication speed, Gestele also has an associated word predictor that is activated while the user is composing messages. The prediction list is in the middle part of the interface (see Figure 4), between the controls relative to the selection of a number of pre-stored sentences (agreement, disagreement, etc.) and the conversational style. Selecting one of the options that are shown in the prediction list means that this option is included as the last word of the message composition, that is, in the text box in the middle-bottom of the interface.

With the aim of enhancing communication speed and minimizing silences during message composition, the system has pre-stored sentences made available automatically, depending on the state of the conversation. Once a sentence is written or selected, it can be then spoken via a commercial speech synthesis system connected to a modem with telephone line connection.

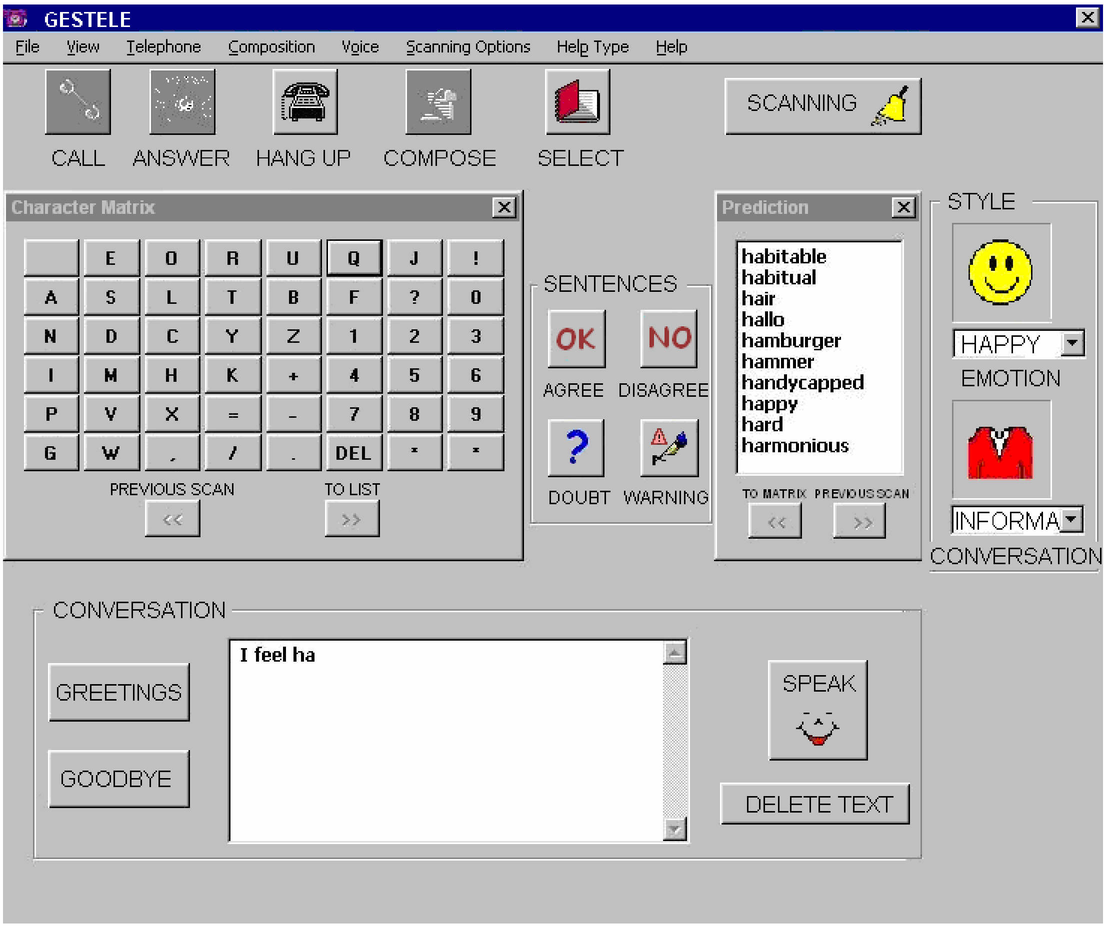

Figure 4. Gestele interface in E4 state of the automaton.

It has a conversation model similar to the one used in the CHAT system (Conversation Helped by Automatic Talk) by Alm et al. (1992) that allows the state of the conversation to be represented internally using an automaton (Garay-Vitoria et al., 1995, 2001). For instance, in an initial state, the system randomly selects a greeting among the stored ones. Then, introduction sentences can be produced, the main topic will be treated and, finally, the interaction concludes with a farewell. The system is also able to speak sentences stored, depending on the state of the conversation; the user controls the evolution of the dialogue at every moment by using the options presented in the interface (see Figure 4).

The main controls of the system are in the central area of the interface. Among them, there are buttons to

- call, answer and hang up
- compose and select a sentence
- speak via speech synthesis and stop the reproduction (delete text)
- generate filler remarks: agreement, disagreement, and doubts
- produce alert sentences to express that a new sentence is being composed, in order to avoid any silence being interpreted as a communication breakdown by the interlocutor
- say goodbye
- activate/deactivate the scanning option.

All these buttons cause effects on the automaton. They also may generate transitions in the automaton, depending on the current state and the required action.

The other controls are used to develop the conversation, but they do not change the state of the automaton. Sentences composed with the editor appear on the right side of the window. There are also two scrolling lists to change the speaker's emotional and conversation style in a simple way. Several utilities are associated with the editor, such as a virtual keyboard on the screen to write messages, either directly or using scan input. A word predictor window shows the most probable words starting with the letters the user has already written, in order to minimize the required keystrokes to compose messages (see Figure 4).

The state bar shows information relative to the controls and program execution. The menu shows all the possible program options. The majority of these options are more comfortable to use via the tool bar; however, several options have to be selected from the menu. The most usual are

- view, to select editor font
- voice options, relative to speech synthesis in order to change volume, pitch and speed
- scanning options, to configure scanning speed.

Sentences selected by the system are shown in the editor and synthesized via voice. It is also possible to voice the text in the editor window. The scanning option is given with the options on the main screen, changing the attention focus after a certain time.

At all times, the system must take the state of the conversation into account so as to offer speech performances with the most appropriate speech characteristics (mainly volume, pitch, and speed). These sentences have a particular purpose in the dialogue and are appropriate only in a given state. In this way, the achievable rate (measured in terms of words per minute) is enhanced and the needed keystrokes to compose sentences are minimized. Depending on the state of the conversation, the improvements achieved may vary. It is evident that in farewells and greetings, the improvements will be higher than in the main topic state. This results from the main topic being particular for each dialogue, while farewells and greetings may serve for the entire set of dialogues. For this reason, as seen in Alm et al. (1992) and Garay-Vitoria et al. (1995), farewells and greetings are more predictable than main topic themes.

Another factor to bear in mind is the expression of personality and conversational style (Garay-Vitoria et al., 2001). The sentences should be adapted to the personality of the user (e.g., personalizing the user's speech). There is a need to study the user's vocabulary and the way he/she combines the words to create sentences with determined structures. The style of conversation is a parameter that depends on the user's frame of mind at a given time, as well as on the interlocutor he/she is addressing. With strangers, the adopted tone is normally formal or polite. With a friend, the tone is more informal and the use of slang is even possible. If the user is angry, the style of the conversation may be more aggressive.

The personalization of the system to a given user is initially done by storing his/her most appropriate sentences to the most predictive affective states. At the beginning, a set of sentences is stored in files or in a database, along with their possible usage (the most adequate moment to make them known, the style of the conversation, the state of mind they are related to, etc.), as mentioned in Garay-Vitoria et al. (1995). The user can include (or remove) new sentences for these states. Furthermore, sentences interactively composed during a given conversation may be stored for displaying in future conversations, whenever the need arises. An added feature is the possibility of storing proper nouns in order to personalize the user's environment, possibly with information related to the way users treat their peers (formal with the boss, informal with a brother, slang with a friend, etc.). In addition, the interlocutor's attention must be maintained while the user is interactively composing a message. In this stage, filler messages are expressed at regular intervals, minimizing awkward silences.

Moreover, Gestele has predefined profiles that may be selected in order to properly express voice characteristics by using the system (see Figure 5). There are five predefined

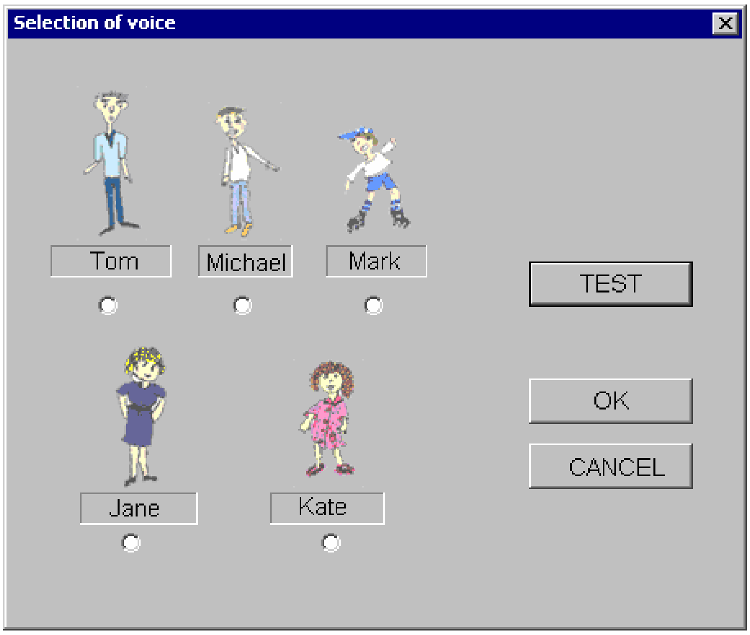

Figure 5. Selecting voice predefined characteristics in Gestele system.

profiles: male adult, male teenager, male child, female adult, and female child. Even though these profiles are predefined, the voice parameters can be adjusted using the previously mentioned voice options tool.

The interface has been designed to be usable and accessible. It is easily learnable (e.g., icons are associated with descriptive labels to avoid confusion); flexible and adaptable (e.g., selections can be made directly or via scanning input by using the keyboard, the mouse, or another input device); direct (e.g., the messages shown to users are clear and concrete); and with enough feedback (e.g., there is an acoustic signal that expresses the beginning of actions in order to make clear to the users when a new action starts). For a better understanding of the Gestele system, we provide a detailed description of a real-use scenario.

Use Scenario

Associated with the E0 state of the automaton shown in Figure 2 is the Gestele interface shown in Figure 3. At this point, according to the automaton, the user can make a call (selecting the Call button in the interface), receive a call (selecting the Answer button in the interface) and prepare a message (selecting the Compose button in the interface). Or the user also can change the configuration characteristics (relative to the voice, the scanning, or similar topics) or explicitly select his/her emotion and the conversation style. Configuration characteristics also can be changed at any moment while the application is running.

To make a call, the user selects the Call button (either directly or by scanning), and is prompted for the telephone number. A new window emerges to write the phone number (see Figure 6). In this new window, the user may directly write the number to be called or select a number from a directory in the system. The current state in the automaton is now E2, and system interface is the one shown in Figure 4.

Figure 6. Making a telephone call in Gestele system.

Next, when telephone connection is established, a salutation or notice is made, and the current state is now E4. When the main topic is introduced, the system is ready to aid in the current specific conversation (E5 state on the automaton). While the interface of the system is quite similar to Figure 4, the Greetings button is not selectable. The matrix options and the prediction list are windows to help the user compose. Windows can be closed if they are not useful (e.g., when the user directly writes messages by using a keyboard or a similar input device). After writing in the text box, sentences can be expressed via synthetic voice and sent through the telephone line by clicking the Speak button. The text box can be cleared by clicking the Delete Text button. The sentence that was just spoken is made available in the text box in order to repeat it very easily if the interlocutor does not hear it and makes a request for its repetition. Repetition is made by clicking the Speak button again. These pre-stored sentences can be selected by using the Select button at the top of the interface. After the main topic, the user will usually say a farewell (the Goodbye button). The automaton goes to E6 state and the telephone will then be hung up and the automaton returns to E0 state and the interface to Figure 3.

Once a conversation is established, the telephone can be hung up at any moment by clicking the Hang Up button. The automaton will return to E0 state and the interface will be the one shown in Figure 3.

Affectivity in Gestele

On the Gestele interface (see Figures 3 and 4), there are two buttons to reflect the user's emotion and style of conversation in which he/she is involved. We have taken four possible values for each of the topics into account. Possible user emotions are happiness, sadness, anger, and neutrality. On the other hand, possible styles of conversation are formal, informal, humorous, and aggressive. This information is used for the automatic generation of affect within the sentences. Depending on these values, the sentences and the way they are synthesized are different. Sentences are stored in a database and categorized in terms of the state of the automaton they can be used in. Sentences are also indexed by the type of emotion and conversation to select the adequate expression on a given context.

Transmission of Affective Characteristics

To reflect the user's emotion, the three parameters (volume, pitch, and speed) used by the voice synthesizers are tuned in the way proposed by Iriondo et al. (2000), Murray (2000), Murray, Arnott, & Rohwer (1996), and Oudeyer (2003) in order to emulate diverse emotions. The most appropriate type of voice for each user can be selected among a set of predetermined voices. These voices can also be adjusted to the user's preferences.

The emotions and the style of conversation change only if the user wants to do so. In this way, the user always has control over the values of these two options. Nevertheless, as reported by Picard (1997), the selection of certain affective parameters may require a tremendous effort for users with disabilities. In order to avoid interrupting the message-writing user with the task of selecting a frame of mind and/or a style of conversation, the use of automatic emotion capture methods is suitable. While the system detects the user's frame of mind, he/she can focus on message composition. Consequently, the system will automatically detect the style of conversation and emotion and adapt itself to the most adequate characteristics of this with a minimum effort on the part of the user (who only needs to supervise the adaptation).

Recognition of the Frame of Mind and the Style of Conversation

To know about the style of conversation, both the user's emotional state and the interlocutor's frame of mind have to be considered. Concerning the automatic detection of the interlocutor's emotion, we have carried out a preliminary study on detecting the volume, pitch, and speed for interlocutors who are able speak directly. We have created a basic model based on fuzzy logic that takes the variations of those factors into account and estimates the interlocutor's emotion. We have established a knowledge base related to various interlocutors and their normal affective values. This knowledge base is used to define certain user categories and to evaluate how the changes in the interlocutor's volume, pitch, and speed are related to interlocutor's emotion. This feature will be included in a future new version of the Gestele system.

Both the user's and interlocutor's emotions have an important influence on the style of conversation. If the interlocutor is a frequent conversant, and therefore in the stored knowledge base, a particular style can be highlighted. Then, taking the user's emotions and the style of conversation once again into account, the most adequate sentences will be spoken (taken from the database of the sentences) with the parameters (volume, pitch, speed) that better express the feelings of the user with disabilities.

Even when the user's frame of mind is established, the system still gives the user the option of directly changing it (using a scrollable list). In addition, the system has a list of certain key words that may reflect the frame of mind. For example, if the user is writing insults, the system should expect the user to be angry. On the other hand, if some of the words are compliments, then the system projects that the user is happy with something or somebody. Of course, this depends on the user's personal characteristics and use of language (as not everybody uses insults and compliments in the same way and, for example, insults are sometimes used in jest). A weighted dictionary of key terms related to particular frames of mind has been built manually.

EMPIRICAL STUDY ON EMOTION TRANSMISSION VIA THE TELEPHONE

In order to apply the Gestele system in communications via telephone, we wanted to know how much the distortion introduced by the use of telephone line, both in natural and synthetic voice, would affect the emotion recognition by the interlocutor. That is, we cannot take for granted that the understanding of expressive parameters via the telephone is similar to the direct hearing of the same voice.

For this reason, we designed an experiment to assess whether the quality lost due to the use of the telephone would affect emotion recognition (Garay, Fajardo, López, & Cearreta, 2005). The TTS engine of Gestele was used to synthesize audio files with different characteristics by manipulating voice parameters. In this study, four emotional states were focused on: neutral, happy, sad, and angry. The objective was to verify whether listeners perceived differences in the understanding of these four emotions in the same phrases heard directly or over the telephone. The hypothesis was that the transmission of expressivity with telephone communication would be less efficient than that obtained in direct communication.

Method

Participants were 25 student and professor volunteers from the Computer Science faculty (University of the Basque Country, Spain), 17 males (average age 33.5 years old) and 8 females (average age 39.4 years old). This preliminary study focused on the paralinguistic parameters of the speech because the synthesized language (English) was different than the mother language (Spanish) of the volunteers. This way, the effect of the sentences' meaning was controlled. In addition, the English level of the participants was surveyed and introduced as a covariate variable in the statistical analyses. The participants' English level was classified following the Spanish standards, as elementary (12% of the sample), intermediate (56%), first certificate (24%), advanced (24%) and proficiency (4%).

Ninety-six sentences reflecting the various paralinguistic emotions were produced. A computer program to gather the results was developed.

Hardware

A Microsoft SDK 5.1 TTS engine was used to synthesize the voice in mono-aural PCM (Pulse Code Modulation). Sentences were uttered in two formats: direct voice quality was presented at 22050 Hz with 16 bits and telephone quality was simulated using 8000 Hz with 8 bits.

Design of the Experiment

A multifactor-within-subject design was adopted. The independent variables were voice type (Direct and Telephone), emotional status presented in the spoken statements (Neutral, Happy, Sad, and Angry), and a combination of three parameters values (Volume, Rate, and Pitch) for emotional status (giving as a result combinations named 1, 2, and 3 for each emotional status). The dependent variable was the rate or correspondence (in percentage) between the answer of the participants and the emotion programmed for the synthetic voice. This variable was called "hits."

A variable that could interfere in the effect of the manipulated variables is the content of the sentences. To avoid this effect, only four types of sentences were used, each reflecting neutral, happy, sad, or angry semantics (see Table 2). Additionally, each type of sentence was combined with the three possible combinations for each emotional status. In this way, this variable was neutralized and was not taken into account in the subsequent statistical analysis.

Table 2. Sentences Used in the Study.

Intention	Sentence
Happy	I enjoy cooking in the kitchen.
Neutral	Wait a moment, I am writing.
Angry	Your mother is worse than mine is!
Sad	I feel very tired and exhausted.

Procedure

Each person was asked to listen to two blocks of 48 sentences each through headphones, and to match each sentence heard with an emotional status. Sentences within each block were uttered one by one as if either directly by the synthesizer or with telephone quality. Half of the participants started the experiment with the block of direct voice sentences and the other half began with the telephone quality; the groups then listened to the alternate block. The order of presentation was randomly assigned to each participant. In the same way, to avoid any dependence, the order of presentation of each emotional status was randomly distributed within each block of sentences.

Each sentence was uttered twice, with a 1-second gap between utterances. After that, participants had to select one of the emotions (neutral, happy, sad, or angry) from a form shown on a computer screen. The next sentence wasn't voiced until the participant answered. Each sentence was presented in the same manner until all 48 sentences of each block were spoken. To ensure the comprehension of the procedure by the subjects, a trial block was carried out before the experimental phase.

Results

With the data obtained, an ANCOVA multifactorial study was performed. Thus, independent variables within subject were Type of Voice (Direct or Telephone), Emotion (Neutral, Happy, Sad, and Angry) and Combination of Voice Parameters Values (1, 2, 3; see Tables 3 and 4)[3]. The knowledge of the English language was introduced as a covaried variable. The percentage of hits was the dependent variable.

The most interesting result was that there were no significant differences in emotion perception for the voice directly heard or heard over the telephone. In addition, a significant effect of the Emotion Type variable was obtained, $F\ (3, 72) = 18.52$, $MSE = 0.14$, $p < 0.001$. Sad obtained $M = 0.80$ hits on average; Angry, $M = 0.70$; Neutral, $M = 0.66$; and Happy, $M = 0.66$. As seen in Figure 7, the emotions Neutral and Happy were significantly harder to detect than Sad and Angry, $F\ (1, 24) = 416.34$, $MSE = 0.12$, $p < 0.001$. In the same way, Sad was significantly easier to detect than Angry, $F\ (1, 24) = 5.74$, $MSE = 0.13$, $p < 0.001$.

Table 3. Generic Values of Synthesized Voice Characteristics.

	Volume	Rate	Pitch
Range	0/100	-10/+10	- 10/ +10
Default	DV=100	DR = 0	DP = 0
Maximum	100%	DR*3	DP*4/3
Minimum	0	DR/3	DP*3/4
Increments	1%	Rate + $\sqrt[10]{3}$	Pitch+ $\sqrt[24]{2}$
Scale	Linear	Logarithmic	Logarithmic

Table 4. Specific Combinations of Voice Parameters Used in the Study.

Emotions	Volume	Rate	Pitch	Combination
Neutral	80	0	0	Neutral 1
	85	0	0	Neutral 2
	90	0	0	Neutral 3
Happy	100	3	8	Happy 1
	80	1	10	Happy 2
	90	2	9	Happy 3
Sad	60	-4	-8	Sad 1
	45	-2	-10	Sad 2
	55	-3	-9	Sad 3
Angry	100	2	3	Angry 1
	100	3	7	Angry 2
	100	2	5	Angry 3

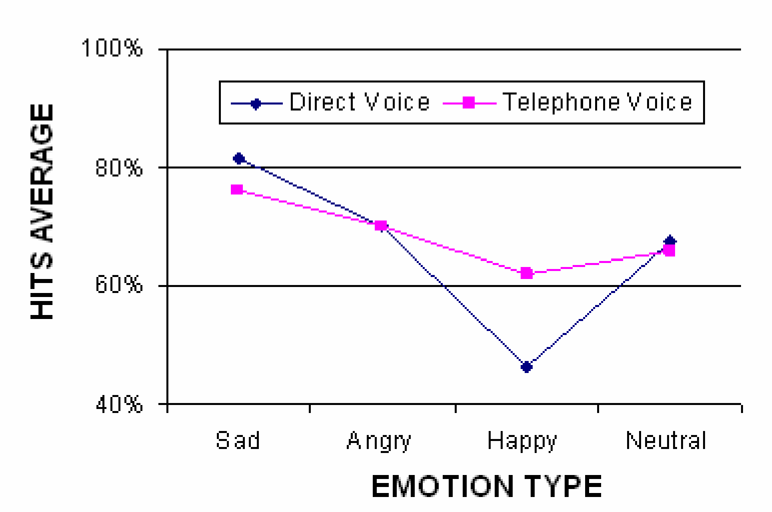

Figure 7. Hits averages (percentages of emotions recognized by users) for each type of emotion condition transmitted via direct synthetic voice or via telephone synthetic voice.

According to these results, we can conclude that the transmission of emotional cues associated with synthetic voice utterances is equally efficient whether the voice is heard over the telephone or directly. In addition, our study allowed us to partially reiterate the results obtained by Oudeyer (2003), showing the manipulation of volume, rate, and pitch parameters of synthetic voice allows for the expression of emotions. Nevertheless, there are certain emotions still difficult to reproduce, especially happiness and neutrality. The emotions of sadness and anger are perceived with better accuracy. The superiority in perceiving an angry expression seems to agree with the results obtained with human voices (Johnstone & Scherer, 2000). In that study, the authors suggest an evolutive explanation: Emotions that express danger, such as anger and fear, must be able to be communicated large distances with the aim of being perceived accurately by the members of the group or by the enemies. In order to do so, voice is the most effective means (as the results reveal), while facial gesture would be more effective for emotions that must be transmitted short distances.

These results must be considered with caution, as the experiment did have several methodological limitations. One of the most important was the lack of comparison with the efficiency of human voice, as both direct and telephone voices were synthetic.

CONCLUSIONS AND FUTURE WORK

Even considering all the advances reached in this area, for computers to recognize, identify, and synthesize emotions in real life remains science fiction at the moment. Nevertheless, this is a possibility that is being refined today. As shown, the application of affective techniques in assistive technology systems to enhance the rehabilitation of, integration of, and communication among people with disabilities is very promising. Most of the efforts so far have been centered in unimodal and unistage interaction; however, there are also studies related to multimodal interactions.

In particular, the work presented in this paper shows that affective mediation may serve to transmit information through mediation systems. This therefore enhances the user's expressive features (by text and speech) and his/her ability to recognize and model messages.

Gestele adds information related to the user's affects and to the style of conversation even over the telephone, thanks to the associated speech synthesizer that modifies various basic prosodic parameters. In order to minimize the effort required by the users to inform their interlocutors about their current emotional state, the model has been designed to adapt automatically, depending on the words used in the conversation. Such a modeling component must be improved and tested with end users (mobility- and speech-impaired people) in the future. Furthermore, other ways for the automatic recognition of user affect are being designed within the many projects LHCISN is involved in. The above-mentioned alternative ways will embrace the rest of the systems of the Lang's (1984) bio-information model, that is, behavioral (facial gestures, speech prosody, etc.) and physiological responses (heart rate, skin conductance, etc.).

Finally, we are working on developing a decision model that allows for integrating and interpreting information taken from diverse sources (e.g., speech, facial gesture, and heart rate), as found in Obrenovic, Garay, López, Fajardo, & Cearreta (2005). Such a significant step is a huge challenge, as little work has been done on how the three response systems described by Lang (verbal, behavioral, and physiological) interact among themselves. From another point of view, the applied research itself may make the basic research easier.

ENDNOTES

1. See, for example, Tegic Communications, T9 ® text input for keypad devices. Retrieved September 26, 2005, from http://www.tegic.com
2. See, for example, BodyMedia, Bio-metric monitoring system. Retrieved September 26, 2005 from http://www.bodymedia.com/products/biotransceiver.jsp

3. This variable was introduced as the recommended ranges of each parameter, for each emotional state is wide and variations in the selected values or combination of values could affect the efficiency of the comprehension of such an emotional state.

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A LIGHTWEIGHT, USER-CONTROLLED SYSTEM FOR THE HOME

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Abstract: *This paper explores how we designed, with input from some elderly persons, a multi-agent user-controlled network for the home. The system was designed to support the elderly in living longer at home with minimal support. We describe how our work attempts to tackle issues such as privacy, control of personal space, and enjoyment within the home. As the number of elderly individuals' increases, a certain amount of information gathering or support may be required to assist the elderly in their homes. However, we strongly believe that we should preserve people's privacy in their homes and ensure that any artifact we propose is seen as enjoyable, aesthetically pleasing and, most importantly, not stigmatizing. We describe in this paper how a lightweight setup, using a multimodal mobile robot, a PDA, and an interactive television, can assist the elderly in the home in an enjoyable and unobtrusive way.*

Keywords: *interactive television, ubiquitous computing, information interface, elderly.*

INTRODUCTION

The aging of Europe's population (by 2020, more than 25% of Europeans will be aged 60+; Lutz, O'Neill, & Scherbov, 2003) will have a dramatic effect not only on our societies but also on technology and product development. This trend will influence the design of high-tech commodities and information and communications technologies (ICTs), such as mobile devices. In addition, the desire of older people to live in their own homes and the decline in institutional living, will drive a growing demand for solutions that allow for aging in place[1] (Corso, 1977). Home solutions based on mobile and stationary ICTs (such as our proposed system) have the potential to satisfy this demand by aiding people in coping with everyday life and supporting their integration into society.

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The Telecommunications Research Center (Forschungszentrum Telekommunikation Wien [FTW]) in Vienna, Austria, is involved in various scientific endeavors, one of which is to investigate and develop multimodal interfaces for mobile devices for next-generation telecommunications. Several partner companies of FTW were interested in building a lightweight, user-controlled network for the home. They envisaged a quite utilitarian design for this environment, which would borrow ideas and elements from existing "smart" homes and similar environments. In contrast to this vision, however, some user-centered design experts believe that technology for the home should be part polemic, part science, part serious, and part fun (Norman, 1988).

Therefore, a better solution for low-level home monitoring[2] may result from undertaking user studies and gaining experience and knowledge from elderly people in their homes. We would like to mention at this point that we did not intend for our resulting design or system to be used by people who have high care needs. This can be done much better with a system of the type suggested by Dewsbury, Taylor, and Edge (2002).

AGING AND TECHNOLOGY

Researchers have found that old age can be split into three stages: young-old age, middle-old age, and old-old age (Namkee, 1999). These stages are less defined by chronological age and more by various social, physical, and mental characteristics. People in young-old age (approximately aged 65-74 years) retire from their work lives and begin to show the first signs of physical or mental weaknesses (e.g., memory problems) even though they are still quite active. People in middle-old age (approximately aged 75-85, equivalent to Peter Laslett's [1998] third age) are still active and quite independent from others. However, impairments or chronic illnesses drive the need for supportive technologies. Old-old age then follows, when weaknesses become so predominant that a person's everyday life is highly dependent on external support from people and technology.

In this context, telemonitoring is an area of growing interest for the Western world's aging societies, as it enables people to live in their own homes for a longer time, rather than having to move to a medical facility or care home (Dishman, 2004). The raison d'être of most telemonitoring projects has been to support patients and care workers in monitoring a life-threatening (Benatar, Bondmass, Ghitelman, & Avitall, 2003) or chronic illness (Giraldo, Helal, & Mann, 2002). One of the main issues in this work is that telemonitoring systems require multiple sensors, devices, and complex network setups (Lukowicz et al., 2002; Sachpazidis, 2002). A benefit can clearly be seen for employing technology with this level of complexity and pervasiveness when the purpose is to monitor patients who have chronic or life-threatening diseases, but the rationale is less persuasive when the person has only low monitoring needs. It could be argued, therefore, that the social aspects of the home must be integrated into the development of supportive home systems.

So far, most research initiatives in the area of supportive technologies for the elderly in the home have been restricted to solutions for discrete narrow-age segments with specific needs, for example, people with severe disabilities and heavy monitoring needs (Lukowicz et al., 2002; Sachpazidis, 2002). However, gerontologists see aging less as a staged sequence and more as a continuous, incremental process (Dharmarajan & Ugalino, 2000), which is characterized by (a) gradual loss of skills—motor, sensorial, cognitive skills (e.g., memory), (b) increasing frailty and (chronic) illnesses, (c) increasing social exclusion and problems of isolation.

Therefore, a home monitoring system should support people seamlessly through all three stages of old age by gracefully adapting to people's highly individual lifestyles, patterns of increasing frailty, and need for support. This is especially important given that it has been claimed (Carmichael, 1999) that designers of products and services tend to patronize and stereotype the elderly, treating them as a homogenous group. In this sense, a truly useful home system should be adaptive, modular, and lightweight.

TECHNOLOGY AND THE HOME

A large number of projects in the area of supportive smart environments tend to permeate homes with pervasive technology. In these approaches, one can see a tendency towards challenging users' abilities with overly complex, hard-to-use devices, as well as interfering with their need for privacy. In contrast, Weiser (1991) proposed a calm technology approach to a more low-level system that supports aging people in their homes. The central issue to remember is that no system should swamp people. People can become anxious and worried at the thought of technology surrounding them and invading their home environments (Baillie, 2002). We should be aware that, in the main, a technology should merge harmoniously into the background of the home and support the user in undertaking tasks. These issues are considered in more detail in the following subsections.

Aesthetics

The attachment we have to artifacts in our homes, and how this can affect the use of such artifacts, has been highlighted by Csikszentmihalyi and Rochberg-Halton (1981). They found that three modes mediate the relationship between an artifact and a person: aesthetics, attention, and goal. The importance of aesthetics has also been found in studies of elders in the home. For example, Hirsch et al. (2000) conducted a study of the elderly and their use of artifacts in a retirement village in the United States. They found that artifacts such as rails to help the elders in their bathrooms were being used as towel racks, as the elders did not want to be viewed in a certain way. They also found that motorized wheelchairs were being shunned in favor of motorized buggies. Why? Because buggies were associated with golf and leisure pursuits, and wheelchairs with creeping old age. Therefore, it could be that having something enjoyable like a robot with a camera undertaking surveillance of the home may be seen as more enjoyable, aesthetically pleasing, and less obtrusive than other artifacts, such as fixed video cameras, monitors, and sensors on the walls.

Control

The issue of privacy and control of space in one's home is important; indeed, it has been commented that architects often forget the importance of spaces in the home and the roles they play (Shapiro, 1998). Rosselin (1999) gives the example of a young student's apartment that had no hallway. The student placed a one-square-meter carpet on the floor beside the door, to suggest a hallway, where guests had to leave their shoes, therefore, making what was one space, the living room, into two spaces, the hallway and living room. How can this ownership and control of space impact our use of our artifacts? Silverstone and Hirsch (1992) thought that technology in the home posed a whole set of control problems for households, such as regulation and control of spaces in the home at different times by different people. Feelings of control or lack-of-control were found to be an important indicator of the participants' feelings towards certain spaces in their homes and the artifacts they contained (Baillie, 2002).

Privacy

Do the assistive technologies and devices that are being proposed for people with disabilities or for elders take into account feelings of loss of privacy? It would seem that people may be willing to give up some of their privacy in order to gain tangible benefits. By putting intelligent devices into peoples' homes, we are opening up the possibility for people to be monitored remotely. Rather than hide or try to camouflage this information gathering from users, it could be much more reasonable to be open about this aspect of the device and let the user control it. People are aware that these devices collect information about them (Baillie, 2002; O'Brien, Rodden, Rouncefield, & Hughes, 1999) and are happy to let them do so in certain circumstances, such as to reveal their health status to trusted persons or to summon help in an emergency. In addition, the possibility of sharing information about their well-being with trusted persons remotely can provide great value for the elderly people and their relatives (Dishman, 2004).

The background research has highlighted a couple of issues that designers should consider when designing artifacts for the home:

(a) That any technology, along with all the usual usability goals, should be aesthetically pleasing and enjoyable to interact with;

(b) The user should feel a sense of privacy and have control over any technology proposed for his/her home space.

THE HOME STUDIES

We undertook three home studies, known collectively as a Home Workshop, involving three households in central Scotland (a full description of the study and its results can be seen in Baillie, 2002). The focus of these studies was to gather requirements for future systems for the home.

Methodology

The home studies focused on what technologies the households currently used but also went further and tried to discover what the individuals wanted for the future. The format of the home visits can be seen in Table 1.

Table 1. The Methods and Focus for a Home Workshop (Baillie, 2002, p. 88).

	Focus	Methods
Home Workshop	Investigate current problems and future possibilities	1.Technology tour 2. Representations of emerging technologies 3. Scenarios 4. Sketches

Undertaking a study in the home was seen as an opportunity for the researchers to learn about the households and the technology contained within them. This was achieved by carrying out a “technology tour” (Baillie, Benyon, Macaulay, & Petersen, 2003), the aim of which was to collect information about existing technologies. The technology tour involves householders taking the researchers on a tour of their homes. Several researchers have pointed out that the way in which technology is integrated into the physical and social organization of the home provides useful clues to understanding the use of technologies (O’Brien & Rodden, 1997; Venkatesh, Shih, & Stolzoff, 2000). Thus this focus was maintained in the technology tours as the researchers asked about possible conflicts in ownership of the space (O’Brien & Rodden, 1997; Venkatesh, 1996) at different times by different family members, as well as the history, flexibility, and motivation for the physical organization of technology within the space. The researchers asked the participants to describe problematic situations they had experienced with their technologies and to show how they used the technologies (Sperschneider & Bagger, 2000). The main thrust of the technology tour revolved around four key issues: what technologies are present in each room, where they are placed, who uses these technologies, and how they are used.

The participants were then shown emerging devices with the aim of stimulating discussion about future devices. The devices included things such as the refrigerator that “knows” when it is out of milk, the microwave oven with e-mail and an i-link (enabling users to link-up various devices, such as the TV, sound system, PC), and so on. This was so that the discussion was not limited to currently existing devices but was also looking towards the future and what might be available in 5, 10, or 15 years.

We then discussed possible future scenarios of use. For example, we asked them to imagine waking up in the morning and having available an assistive system. What could they imagine it doing or how could it assist them? Scenarios can be used to facilitate the creation of sketches and more involved user participation in the development of a design. In addition, scenarios can be as flexible, informal, sketchy, or as structured as needed.

Finally the participants were asked to sketch a future device for the home that they would like to have. There were three reasons why they were asked to envision their own technology for the home. First, home technology at the moment is mainly built and designed from the manufacturers’ rather than the user’s perspective. Second, it was hoped that by asking the participants to think of their own solutions it may help them and us to envisage some novel ideas for designs. Third, the sketches would provide a way of extracting and learning about the needs and wishes of the participants and could help some of the more diffident participants to create an overflow in their imagination, as described by McKim (1972). Therefore the home session was split into four separate but overlapping parts.

Procedure

Each household was visited on three occasions at mutually convenient prearranged times. The households involved can be seen in Table 2. Pseudonyms have been used for the participants.

While it could be claimed that the Cooks were too young to take part in a study about a system designed for the elderly, we thought that it was important to include them, as they would soon be reaching retirement age (in Scotland, the retirement age for women is 60 and 65 for men). It was anticipated that they would be able to provide information on new retirees who may be more technologically knowledgeable. The other participants could be said to meet

Table 2. Households Involved in Requirements Gathering.

Identifier	Who		Age	Occupation
Cooks	Robert	Husband	60	Senior lecturer
	Sue	Wife	55	Housewife
Suttons	Emily	Wife	70	Retired teacher
	Peter	Husband	72	Semi-retired builder
Reilly	Agnes	Widow	84	Retired cook

the criteria of middle-old age. Equipment taken to the homes for the interviews comprised a video camera, pens, paper, art materials, and a notebook.

Findings from the Home Studies

A very small selection of the sketches (drawn by the participants themselves) and comments made by the participants are presented in this section. In the sketches, the control issue was elucidated by the participants wanting to know more about what was going on in their homes and who was "in" them when they weren't there. The concept of security spanned further than securing the home from burglars, by also encompassing the well-being of family members and the ability to contact the emergency services. For example, Agnes wanted her device to be used in the event of a fire or an emergency. She anticipated that the system could be accessed by the emergency services to let them know who, if anyone, was in the building (see Figure 1).

Agnes also wanted her device to enable her to see and monitor her home when she was not present. The idea of the device came to her because of her frustration about not being able check on her home when she went on a holiday in the United States. She made it very clear that only she should be able to control the access to the monitoring system for her home.

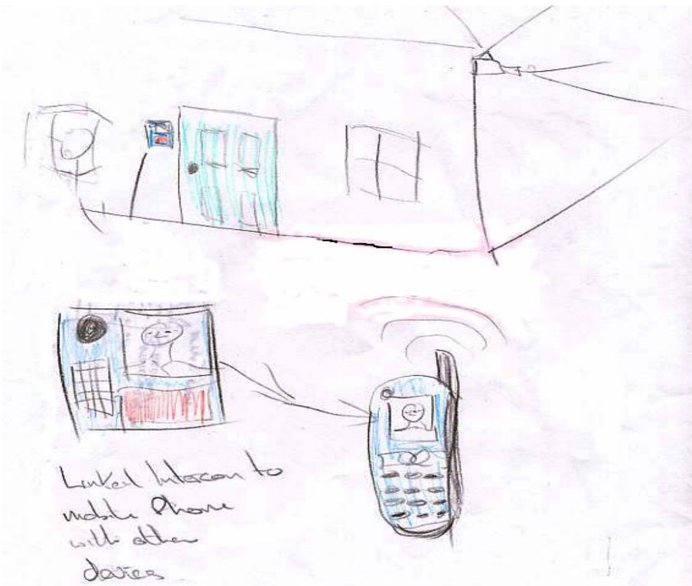

Figure 1. The device concept drawn by Agnes is a remote home monitoring device.

Meanwhile, Peter wanted a device (see Figure 2) that would alert him if he had left devices on in a room, for example, the television, cooker, or lights. He mentioned that he was becoming forgetful and that he would find a device of this type very useful. He felt very strongly that he did not want an artifact taking up space and dominating his home. Peter also remarked that if the other houses on his street were wired to this system, they could have a communal warning and message system to aid communication.

Some researchers have suggested that people may benefit in unanticipated ways from linking homes and private spaces in this way. For example, Blythe, Monk, and Park (2002) suggested that social connections, which have been lost over time, could be reactivated by using local on-line street maps that would help householders keep in touch with their local surroundings and chat with neighbors. The fact that a senior citizen designed a device that would help him as he grows more infirm and forgetful is of interest, as many researchers at the moment are looking at building smart homes and trying to understand what senior citizens would want from this type of home. Therefore a clear benefit to researchers and to senior citizens can be seen if the designer/researchers involve senior citizens in the actual design process rather than only thinking of them as a source of data.

In our home studies, the seniors also mentioned that they did not want the monitoring system to be too utilitarian or stigmatizing. Peter wanted one of the interaction devices to hang on his wall like a picture. He wanted the functional interface to disappear when not in use and a photograph of his daughter and grandchildren to appear. Agnes thought “those funny dogs from Japan” (AIBOs) would be a good idea. Our home studies demonstrated that

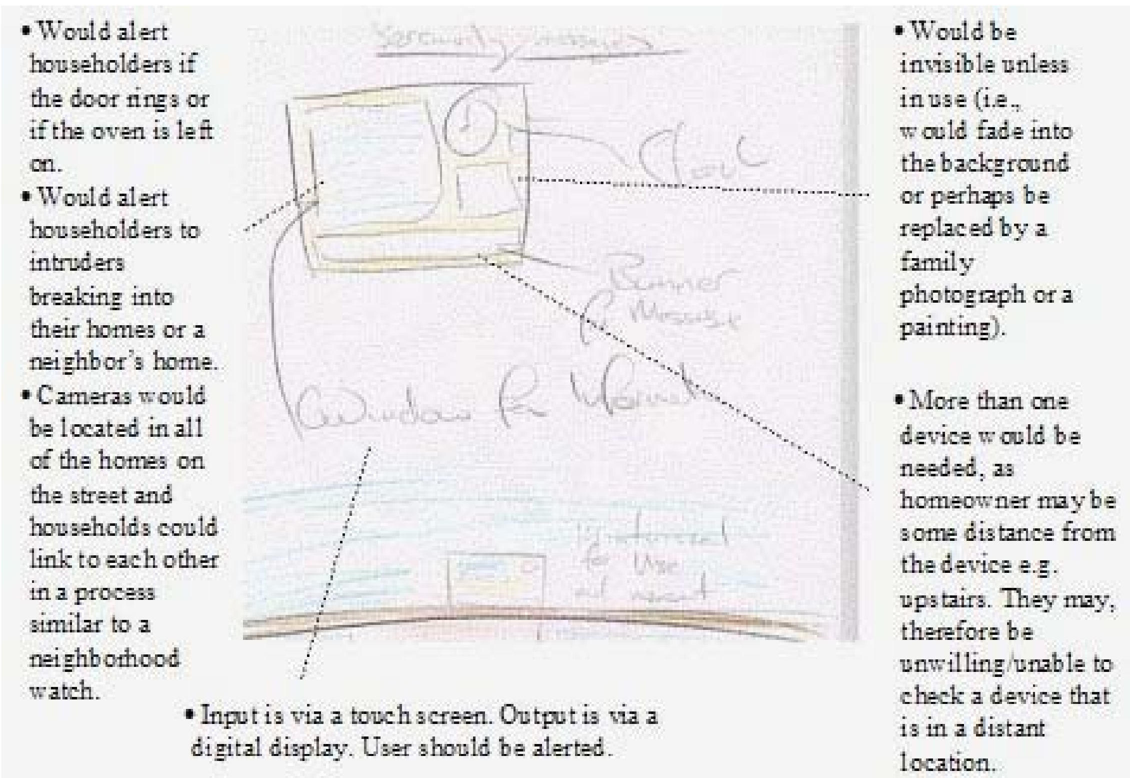

Figure 2. The device concept drawn by Peter.

the elderly were quite capable of coming up with new and interesting ways in which their homes could be monitored without the need to install permanent cameras and sensors, which could be seen as obtrusive and not in harmony with the aesthetics of the home.

The findings from the studies led us to believe that a device that would provide some level of home monitoring would be more welcomed by users if it had the following attributes:

- It could be accessed and controlled remotely, either via a mobile device or the Internet;
- It was unobtrusive (merged into the background) and did not take up space in their home or affect its fixtures or fittings;
- It allowed for privacy and its control rested with the householder. The householder would be the only one to relinquish this privacy and control, should he/she wish to do so.

THE PROTOTYPE SYSTEM

While many devices and concepts were envisaged during the development of our prototype system, none could be said to offer all of the wishes expressed by the householders. However, all of the core concepts expressed by the interviewees were used in the design process, meaning the resulting system provided a way in which to monitor a home remotely and in an unobtrusive manner while keeping the control of the system with the householder or whomever he/she decided to give access.

Our design for the system was also influenced by Carmichael (1999), who found that designers tend to patronize the elderly and treat them as a homogenous group. We tried to avoid this pitfall by conceiving technologies that would meet the specific, yet diverse, needs of the elderly.

The findings from our home studies led us to include a mobile device and the Internet in our system, thus allowing the system to be accessed and controlled remotely. Numerous research findings have shown that older adults are interested in the Internet. In fact people aged 60+ are the fastest growing age group on-line (Fox, 2004). In addition, Dewsbury et al. (2002) found that if the elderly are offered a communication aid that doesn't fit into a pocket then they often choose not to carry it. We concluded, therefore, that an appropriate device to meet this condition was a mobile one.

The wish for unobtrusiveness and non-stigmatization led us to include a more traditional technology, the television. There were two reasons for this: The TV is already in most people's homes and our home studies revealed that it was a highly esteemed artifact in the home of our elderly users.

We also wanted to include an enjoyable and lightweight monitoring device to the system. To this end we investigated the possibility of a small robot. We thought that this may be a reasonable solution, as research by Friedman, Kahn, and Hagman (2003) indicated that elderly people felt comfortable using (as well as ignoring) robots and similar devices in their homes. Another reason was that it can easily be picked up and put in a cupboard, thus fulfilling the prerequisites of not affecting the fixtures and fittings and helping the elderly person not feel stigmatized.

Therefore the main elements of the system we developed were (a) a smart device (Smart Phone/PDA) as a mobile assistant, (b) a mobile ambient intelligence unit (the multimodal robot), and (c) an interactive TV set (see Figure 3). These three elements are described in more detail in the following sections.

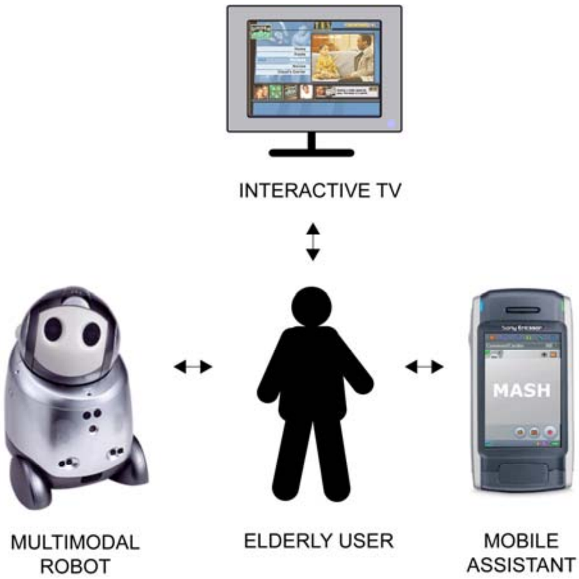

Figure 3. The first concept of the system.

Multimodal Robot

Multimodality promises natural user interaction with devices and applications. Because human communication is multimodal, a device that operates with multimodal communication is perceived as natural and intelligent. These properties are relevant to building easy to use and enjoyable interfaces and applications. The robot was built using the Mindstorms kit (Lego n.d.). The robot can move around and has touch, temperature, and vision sensors, as well as a Web cam. To enable communication between a web server and the robot we installed the Lejos Java Virtual Machine[3].

The behavior of the robot, including the navigation, was implemented according to the behavior control theory by Bagnall (2002). The users can interact with the robot using verbal communication, that is they can give it voice commands such as "go to the kitchen." The users can also control the robot via a multimodal user interface available on their television and a PDA/Smart Phone (the user can choose whether to use a PDA or a Smart Phone).

The interface, as configured for our tests, showed an interactive map of the rooms in the test home and where the robot was located. It was possible to send the robot around the home and let it fulfill different tasks, such as measuring the temperature and checking whether the lights were on or off.

The robot can also function as a watchdog and as the user's remote "eye" in that it can be accessed via a mobile device when user is not at home. Dewsbury et al. (2002) commented that these types of sensors would provide the first level of support to someone who needs a low level of care.

Mobile Assistant

The core purpose of the mobile assistant was to provide the home system with a portable, lightweight interface. Through the Web interface noted above, users can remotely control the multimodal robot independent of their own location. However, today's mobile interfaces (i.e., tiny displays and keys) present serious challenges to elderly people with their more demanding physical requirements. Therefore, voice input and output were provided as alternative modes for our system. Another reason for the inclusion of a Smart Phone in the mobile solution was the need for telecommunication capabilities, for instance, to summon help quickly and efficiently when required. Other research (Dewsbury et al., 2002; Lundell, 2004), as well as our own studies, have shown that elders have no problem with using portable technology that offers assistance inside and outside their homes. Again the design guidelines provided by Carmichael (1999) for the elderly were followed.

For testing we developed an interface for a PDA (see Figure 4). This device allowed a user to control the system using a multimodal user interface that showed a map of the rooms in the test home and where the robot was located. The user could also interact with the system via the TV using the TV remote control.

Figure 4. The PDA on the left shows a map of our mock-up apartment at our research center. The PDA on the right shows the current temperature in the living room of the apartment.

Interactive TV

Studies have found that the television is an elderly person's preferred channel of media consumption and that it is a well-established element in the home environment that enjoys a high level of user acceptance (Andrew, 1999).

In addition to its normal purpose, the television can be used as a large display unit. Using a TV set as an alternative display unit should alleviate some of the problems that people with visual impairments have with mobile devices (e.g., small font sizes, need for scrolling, and low contrast). Also, a TV could help the hard of hearing, as users are familiar with adjusting the volume controls via their TV remotes and TV sets offer surround sound and other sound features. For these reasons, an interactive TV set was included as the third component of the home system. It was additionally anticipated that as an elderly person became more used to the features of an interactive TV, they may in the future use the TV as a communication device (e.g., for video conferencing or Web browsing.)

EVALUATION OF THE PROTOTYPE

We organized a small user test of our system. First, we wanted to investigate whether or not the system could in fact be operated using voice commands and if these voice commands were carried out effectively (i.e., if the user told the robot to "go to the kitchen and check whether I left the cooker on," did the robot indeed go to the kitchen as commanded and report back?). The second part of the study focused on the usability of the system. That is, whether or not the simple tasks highlighted by the earlier home studies could be completed (e.g., turning lights off that had been left on accidentally).

The system was tested at our research center in a mock-up of one of our home study participant's residences (see Figure 5). Therefore, the system did not face a true field test. While a simulated environment would not be the ideal setting in which to test the full system, it was appropriate for undertaking experiments at such an early stage of the system's development.

Figure 5. The robot located in the mock-up living-room at our research center lab.

Aim of the Evaluation

The aim of the user evaluations was to uncover the following:

- Do the users, in general, find the technology attractive and useful, meaning can the system with its various components meet real needs for lightweight monitoring in elderly people's homes?
- Is the technology understandable and easy to operate? In particular, we examined whether
    - the available functions are immediately perceptible in a way that supports the user's spontaneous understanding of possible and/or necessary opportunities for action;
    - the user continuously receives relevant and immediately understandable feedback from the interface and guidelines for further action in the course of interaction;
    - the system supports the user's navigation in such a way that the user always knows where they have been, where they are at the moment, and where they have the possibility to go in the overall information space.

Because the system is supposed to be used by people perhaps unfamiliar with contemporary technologies, employs a range of devices, and performs a wide range of tasks, we consider success in these testing criteria as prerequisites for an enjoyable user interaction. When technology draws on the highly developed human capabilities for immediate perception and comprehension of a large amount of information about the physical world, and exploration and manipulation of this physical world are permitted, the technology has the potential of being a "transparent" tool[4] for information in the course of everyday tasks.

Methods and Procedures

With the aim of uncovering usability advantages as well as usability problems, the prototype was evaluated in the following way:

- Explicit focus on the interaction modalities: touch, voice, and pen, which were evaluated in our research lab mock-up home with real users employing the "think aloud" process for usability tasks, and an interview;
- Focus on general use of the system, evaluated in a laboratory testing with real users (couples) employing the "co-discovery" process, usability tasks, and an interview.

The basis of these tests was the user tasks and scenarios created from everyday tasks, as elicited from users during the home studies. Any problems uncovered were used to create recommendations for correcting or enhancing the interface and its functionality.

We undertook testing with the users in the interaction laboratory at FTW. We expected the investigation to be explicitly focused on the interaction modalities and assumed a motivated user. We carried out six laboratory test sessions, with eight users. We believe that this number of subjects was sufficient to uncover all the major usability problems, as do other researchers (Dix, Finlay, Abowd, & Beale, 1998; Nielsen, 1993). The users were aged 65 to 80 (average age 72); their gender, previous professional status, and technical expertise were balanced, meaning we tried to include people with a range of skills and an even split of male/female. The first four users carried out a semi-structured set of tasks (Table 3) reflecting the scenarios of everyday use situations and employing the procedure of "think aloud," followed by an interview. *Think aloud* is a process used during evaluations in which the

Table 3. Usability Tasks and the Time Allocated to Perform the Tasks.

Usability Task 1: Start the system on the TV.	3 min
Usability Task 2: Explore the elements of the system.	7 min
Usability Task 3: Send the robot to check whether the cooker in the kitchen is on.	3 min
Usability Task 4: Listen for a response from the robot and act upon it.	3 min
Usability Task 5: Send a verbal command to the robot (e.g., go to the living room).	3 min
Usability Task 6: Change the household heating temperature by using the PDA.	3 min
Usability Task 7: Shut down the system on the TV.	2 min

users are encouraged to talk to the evaluator and discuss freely the problems they are having with the system. By using this technique the users see themselves as collaborators in the evaluation and not simply as experimental subjects. This also allows the evaluator to ask the users questions. According to Dix (1998), this form of evaluation has two advantages: the user is encouraged to criticize the system, and the evaluator can clarify points of confusion at the time they occur and so maximize the effectiveness of the approach for identifying problem areas.

The next four users comprised two couples, and we therefore felt that it was appropriate to use a slightly different methodology. We used the co-discovery procedure, followed by the usability tasks, and then an interview. The primary difference between the co-discovery method and that of the thinking aloud method is that the *co-discovery test* is carried out with the participation of two test persons, who explore the technology on their own without a test leader present. The test persons are supposed to know each other well and explore the technology in an unstructured and cooperative manner. We felt that this was an appropriate methodology for couples and would further provide us with a degree of ecological validity in that some of the households we were concerned with could have two adults who could be expected to explore a new device jointly. An evaluator observed the co-discovery test users' exploration of the technology and completion of the usability tasks.

All the sessions with users were videotaped. We undertook a further analysis of the data and the videotapes with three usability experts (one who had 5+ years experience and the other two who each had on average 2.5 years experience). One expert was working on the project, the second worked for the research center but on different projects, and the final expert was from outside the research center's staff.

Results from the Prototype Evaluation

The analysis of the overall evaluation of the prototype was expected to uncover usability advantages as well as usability problems. These were then expressed in recommendations for correction of detected problems or to enhance the design of the user interaction or interface.

Due to technical problems in one test, the data of seven subjects was considered for analysis. It should be pointed out that the testing and the user experience suffered from the immaturity and the early development stage of the prototype provided at the time of testing. One of the most striking problems in this regard was the long latency of system reactions to switching or selecting options on the different devices. Other problems relating to prototype immaturity were missing functionalities (audio features, settings) or insufficient content quality and quantity (e.g., maps and help instructions).

Results from the co-discovery testing

In the co-discovery part of the evaluation, the couples were particularly inventive in their requests to the robot and sent it all around the lab, trying to get it to go through doors and around objects. They were found to do this even when they did not have a clear idea about what the system did or how to complete a task. Three of the four users thought that they would like to use such a system in their homes.

These test participants found the concept itself quite valuable. Users emphasized positively that the system would support them in their daily lives. However, the user experience suffered from the quality of the system prototype.

There were significant problems in the conceptual and graphic design, which need to be addressed in further development. The main navigation bar was very irritating for the users. Also some of the icons turned out to be difficult to recognize and their aesthetic appeal could be increased. It often turned out that the users did not intuitively understand the meaning or function of certain system parts (e.g., the exact difference between "Applications" and "Items"). Another general problem was the semitransparent mapping of the commands to the remote control buttons. Several severe usability problems were observed during the test and were also mentioned by all participants in the interview. In the next section, the results are summarized for each usability task. The findings reported are from both groups.

Results from the Usability Tasks

Task 1: Start the system on the TV.

Only two test users immediately found the correct button to start the system without any assistance. The remaining users looked in vain for the correct button. Most users thought that the on/off button of the remote control would turn the system on or off. The test facilitator asked the test users which additional buttons they thought may also possibly turn the system on or off. The users suggested the menu button, some numbers from the number block, and the channel buttons. The participants who were engaged in the co-discovery spent a longer time than those users undertaking the tasks individually to find the correct button before asking for help. After receiving help all of the test users could start the application.

Task 2: Explore the elements of the system.

- PDA: When asked about what they thought they could do with the PDA, most test users correctly understood that they could access the different devices via the PDA and control them. One person supposed that it might be the only way that information could be updated.
- Robot: Almost all participants understood that the robot could be sent around the apartment. Some of them experimented straight away with trying to send it to various rooms via the map on the PDA screen.
- Menu: Behind this function the users expected numerous different things. Apart from issuing commands and updating the system (the most frequent answer), they also thought that they may find other home monitoring applications and the ability to add their own rooms and maps.
- Settings: All test persons understood that under this menu item they could change the settings.
- Navigation: It could be observed, and many test users stated this, that the navigation around the menu system on the TV and on the PDA sometimes confused the users. Therefore, our design did not meet one of our aims, that is that the system should support the users navigation in such a way that the user always knows where they are.

Task 3: Send the robot to check whether the cooker in the kitchen is on.

- All but one test person could accomplish this task without effort or assistance. The majority of the users (5) selected to do this via the TV and a smaller number (2) decide to use the PDA. Nearly all users (6 out of 7) completed the task of sending the robot to the kitchen. During this task, the extreme latency was noticed and criticized by the test persons for the first time.

- Sometimes the command was ignored by the system and even after restarting the whole system this problem remained. Two of the users had to try several times to find out if the cooker was on.

Task 4: Listen for a response from the robot and act upon it.

Finding the "listen" button on the remote control caused the most problems. Two thirds of the users understood the function of switching the audio feature on and off. More than two thirds saw the speaker symbol when turning on the feature. The remaining subjects held the button or they had the function permanently activated. However, when they did get a response they were able to hear it and act upon it.

Task 5: Send a verbal command to the robot.

Although the majority of the test persons fulfilled this task successfully, only half thought that they had fulfilled this task successfully. The reasons for this varying result were that the subjects didn't know whether the robot had received the command, and the users didn't know, due to the latency, whether the robot was actually acting on it.

Task 6: Change the household heating temperature by using the PDA.

Two test users thought that they had not accomplished this task, when in actual fact they had. The lack of feedback here was crucial to the users' satisfaction with the system and their perception of how they had performed. A major problem for the users was the navigation through the menu items. It can be seen therefore that another of our main aims was not met, that of the user receiving relevant and immediately understandable feedback.

Task 7: Shut down the system.

Many subjects looked in vain for the correct button on the remote control to close the system. This was perhaps due to the fact that the button was not the usual on/off button on the remote control but another button. It was also a different button from the "on" button. When asked whether they thought that they had successfully switched off the system, five thought that they had but weren't sure if they had turned off the robot and PDA as well, and two thought that everything including the television was turned off (e.g., PDA, Robot and TV). When asked whether they thought that any of their data or settings had been saved when they switched off the system, the majority of the test persons thought that after switching off the system their settings would be stored.

General Evaluation

In general, the test participants found the concept of the system itself very interesting and the technology attractive, commenting that they found the robot particularly enjoyable to interact with. Users emphasized positively that the system supports different modalities and that the user can choose the different interaction mediators (e.g., television, PDA, robot).

The users found nearly all of the available functions and were able to understand, interact with, and complete the tasks (albeit sometimes after receiving help from the observer) on the various devices. Particularly during the co-discovery sessions, we found that the users spontaneously found additional functions and operations for the devices, and this was found to be supported through the very interaction with the technology. This was not the case with the individual users, who required more help and guidance from the observer.

All the users found that the system provided opportunities for exploration and manipulation, that is, the actions taken were found to be modifiable and/or reversible. The majority of the users said that they preferred to receive feedback from the robot (we think this is perhaps due to its novelty value), as opposed to the television or PDA.

Certain evident problems (latency, design, and navigation) were brought up by all the participants in the interview session. In this way, the interview data helped to underscore what was observed during the sessions. There were significant problems in the navigation design, which would need to be addressed in any further development. Also some of the icons turned out to be difficult to recognize and lacked aesthetic appeal. It was also learned that the users did not intuitively understand the meaning or function of certain system parts.

CONCLUSION

The paper started out by saying that the companies who sponsored our research wanted us to concentrate on more utilitarian concepts for the home. After undertaking background research, we discovered that a more expanded brief was required to ensure the success of our proposed home system. We, therefore, included other issues of importance to those using such products in the home, in particular aesthetics, control, privacy, and fun.

In order to ensure the usability and acceptability of our system, we undertook some requirements gathering from home studies that involved three households in central Scotland. The focus of this study was to elicit ideas from the senior participants about what type of home system they would like. We found that including the seniors in our requirements gathering led to more fun and unusual suggestions. For example, we had anticipated that a mobile device might not be welcomed by senior citizens, but their design sketches (see Figures 1 & 2) showed us that they would be happy to use a mobile device if there was a need for it. The seniors also mentioned that they did not want the monitoring system to be too utilitarian or stigmatizing.

We tried to avoid the pitfalls of patronizing the elderly and treating them as a homogenous group by providing technologies that would meet the specific needs of this diverse group. The findings from our home study, supported by earlier research, led us to include a mobile device and the Internet in our system, thus allowing the system to be accessed and controlled remotely. The television was chosen as one of the interaction devices because it is already in most people's homes and therefore meets the stated wish for unobtrusiveness and non-stigmatization. Our home studies also revealed that the television was a highly esteemed artifact among the elderly users.

A small robot was included in the system as an enjoyable and lightweight monitoring device. Earlier research (Friedman, Kahn, & Hagman, 2003) had indicated that elderly people felt comfortable using and also ignoring robots and similar devices in their homes. A robot was thought to be a useful solution as well, because it can be picked up easily and put out of view, thus not affecting the fixtures and fittings and helping the elderly person not feel stigmatized.

Finally control of the system was designed to rest with the householder or whomever he/she decides to give access. This, too, fulfilled the seniors' desire that they not be treated in a condescending way.

There were some concerns about whether our elderly participants would adopt such a new innovation and thus we undertook a user evaluation. However, we firmly believed, like Dunphy and Herbig (1995), that the elderly will be more willing to adopt a new technology if it meets their needs and the benefits in using it are effectively communicated.

In the evaluation part of our study, we found that the co-discovery method worked best and elicited most of the insights from the usability testing. Also, the users in these sessions seemed more relaxed about criticizing the system and trying out different functionalities. We would, therefore recommend this method to any other researchers who are undertaking research in this area. The users said that they enjoyed using the system and the three experts who reviewed the videotapes of the user interactions with the system agreed that the users looked happy and relaxed; they even went as far as to say that the users looked like they were having fun.

The overall evaluation found many usability and functional problems with the original prototype, such as navigational errors and problematic icons, which were mainly due to the system's early stage of development. We have since resolved most of these issues and will complete a new version of the design in the near future.

In general, the test participants found the concept of the system interesting and the technology used attractive. The robot was viewed by the users as being the most engaging part of the system and this was the part of the system that they chose as the most attractive to interact with. Of course we are aware that this could be due to the novelty value of such a device and that a home-based study may show that this interest does not continue over a lengthier period of time.

In conclusion we found that it is not always necessary to design solutions that are primarily utilitarian in nature for home monitoring. It can also be useful to think of using devices that have been developed for fun and amusement and put them to a more utilitarian use, such as the robot. There are and will be in the future an increasing number of different types of lightweight mobile monitoring systems for the home. Therefore, it is crucial that the community for whom these artifacts are built contribute to the discussion of what assistive technologies are appropriate and desired in the home. With the intention of addressing this issue, we presented our prototype of a multi-agent, lightweight, user-controlled network for the home for supporting the elderly.

ENDNOTES

1. Aging in place is a concept that favors giving older persons the opportunity to remain in their own homes rather than be cared for in an institutional setting. The improvement of housing conditions and associated services that enhance the mobility/accessibility of the elderly and which contribute to improving their physical/mental condition is critical to sustaining people's level of activity necessary for maintaining independence and quality of life.
2. Low level-monitoring is a system that provides information such as whether the lights are on or off and what the temperature is in certain rooms.
3. See Lejos (n.d.). Lejos–Java for the RCX. Retrieved February 10, 2006 from http://www.iau.dtu.dk/~lego/lego3/rcxcomm/

4. Having a transparent tool is a precondition for having a conscious focus on the goal of an ongoing task, meaning the user is acting without thinking about the operation.

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ENHANCING THE USABILITY OF TELECARE DEVICES

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Abstract: *Demographic and sociological changes in the last 50 years have forced Western societies to create services to attend to elderly people in their homes, where they can live within familiar environments. Telecare involves a device plugged into a telephonic network that provides access to teams of professionals who can attend to the needs of the elderly in their homes. These devices have been designed according to the principles of universal design, but the great number of erroneous calls to telecare centers point to the necessity of enhancing the usability of the devices. One analysis of the cognitive functioning of elderly people showed that a possible cause of these errors could be the difficulty elderly people have when processing language. In our experiment, we tested the hypothesis that the numbers of errors could be reduced by using icons instead of words in the device interface. The results support this hypothesis.*

Keywords: *telecare, usability, elderly people, cognitive deterioration, universal design.*

AGING AND SOCIETAL CHANGES IN CARE GIVING

Among the most important changes that have taken place in today's Western societies are those that result from the exodus from countryside to the cities, the new model of the nuclear family, the changing role of women, and the democratization of family relations. An important consequence of these social changes is that the family is no longer able to satisfy certain needs of its members, mainly because the role of the woman in the family has changed to encompass functions different from what has been traditional.

These social changes are especially relevant in relation to the phenomenon of aging. All around the world, but more so in the most developed countries, there is a constant increment of human life expectancy. This sociodemographic phenomenon means that society has to

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confront the challenges of helping elderly people, who experience a decreasing capacity to care for themselves, to carry out their daily life activities. For this reason, societies have developed social service systems to care for or assist the elderly.

To face these challenges a new research field called *gerontechnology* arose, with a mission to develop products and services adapted to the phenomenon of aging. Gerontechnologists are interested in technologies that help to anticipate (and prepare for) the functional decline that is produced by aging. Therefore, gerontechnologies are designed to enrich the functioning of elderly people, especially in communication, education, and work. In few words, gerontechnology is a field of study in which professionals work to design technologies to compensate for the losses associated with aging.

A central concern for gerontechnology research is to determine the characteristics that an interface of any device must have so that the difficulties derived from aging can be avoided. Said in another way, the focus of the research is to determine what implications aging has for the design of an interface.

Telecare is a set of technologies that provide help to dependent, especially elderly, people by providing access to teams of professionals who can attend to the client's needs 24 hours a day, 365 days a year via a telephonic network. The goals of these technologies are (a) to provide a system that allows the elderly to obtain and to maintain a greater degree of autonomy and well-being in their homes; (b) to facilitate the permanence and integration of the elderly within their social and family environments, thus avoiding many unnecessary situations in which the elderly are uprooted and cared for in an institution; (c) to provide the elderly with security and prompt attention in cases of emergency; and (d) to support the family members who assume the role of supervising their loved one's care.

Telecare came about to solve the problems associated with previous technologies, such as telewarning, a system connected to the telephone that allowed a person to call for help in situations of emergency. This telewarning technology, developed in the 1980s in countries that were pioneers in this kind of social service for helping people in living alone at home (the Nordic countries, Great Britain, and Germany), and similar systems, like the so-called Hope Telephone, were intended to solve many communication problems, as well as to ease the sense of isolation and loneliness that often accompanied the elderly living alone. However, several problems could not be solved by the human operator who answered the call. A study conducted from 1987 to 1991 in France by Templier, Lanata, Baer, and Pasteyer, (1992) showed that 77% of the calls were not emergencies, but were registered as "error of manipulation" or "call to chat," meaning the caller initiated contact with the service for reasons other than an emergency need and the operators couldn't determine if the call resulted from an error or the caller's simple desire to chat.

Furthermore, other difficulties exist, such as falls, diseases, or suffering an assault, that are very frequent situations of vulnerability experienced by elderly people. For example, some studies (Lázaro del Nogal, 1997) have revealed that 25% of those who surpass age 65 experience fall throughout the year. In Spain alone, about 2 million falls and 90,000 fractures each year have been reported (Lázaro del Nogal, 1997). The falls have ominous effects on the person's autonomy, which can be mitigated with fast and diligent help. Nevertheless, there is empirical evidence (Instituto de Migraciones y Servicios Sociales, 1996) that shows that elderly people who fall at home often remain on the ground, far from the telephone, for more than one hour before being able to request aid. As a consequence, the gravity of the fractures increased and the period of hospitalization was greater, both of which increased the psychological upheaval of the person due to the fear of falls, isolation, and dependency.

Therefore, to overcome the problems observed with the use of telewarning and similar systems, UNA (Union Nationale de l'Aide, des Soins et des Services aux Domiciles, n.d.) has elaborated a report with a set of deontological principles for designing new systems for care giving in France that have been applied in other countries as well. The report recommended eliminating systems that only transmit emergency calls from the elderly. Instead, government agencies should look for services that care for all aspects of the life of the dependent person. As a consequence of the application of these principles, a new system called telecare was designed.

Telecare hardware consists of an apparatus wired to the telephone network that has two terminals, one fixed (domiciliary unit, see Figure 1), and another one in the form of a pendant or bracelet (terminal wireless, see Figure 2).

Whenever users are in a situation of urgent help (e.g., they have fallen in the shower), need information, must request some service for themselves or their home, or simply want to know what is on their agendas for the day, they press the corresponding button. For example, telecare users may need to be reminded that they have appointments with their doctors, or that they have to take their medications. By pressing the appropriate button, a user gets in contact with the telecare center where a central computer contains all the sociosanitary histories (e.g., health, family, and environmental conditions) of the user. Special software allows the teleoperator to see on the computer screen immediately the relevant data about the user (data personal, clinical diagnoses, treatments, medicines that she/he takes, name of the health professionals who care for her/him, and contact information for his/her family, reference person, close friend, etc.). With this data, the teleoperator can decide whether to provide a solution to the caller's request with public resources or with private resources (external). Within the telecare center, social workers, medical doctors, psychologists, and so forth, are available to assist the teleoperators.

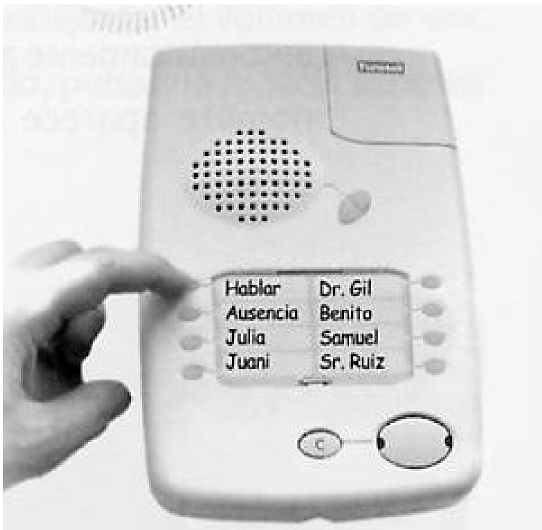

Figure 1. Fixed Telecare Device[1].

Figure 2. Wireless Telecare Device.

THE DESIGN PROBLEM: ERRONEOUS CALLS

Telecare systems have proved to be a very successful tool for providing help to dependent people and for this reason they are being implemented rapidly in many societies. However, some problems have been detected that need solutions before we can say that telecare systems are truly useful tools. One problem is the enormous number of erroneous calls that have been observed. Erroneous calls are defined here to mean calls by seniors to the service centers for any reason other than what the call-button designation indicates: This encompasses issue of "unwanted calls" (including calls to chat), misdirected calls (caller needed a service other than what the designation button indicated), or calls made in error (button pushed accidentally and so the call was unintended). Figure 3 depicts the number and percentage of calls classified as erroneous received during 2002 and 2003 at the Andalusia Service of Telecare (located in Seville and providing services to users from the Andalusia region in southern Spain; Fundación Andaluzza de Servicios Sociales [Andalusia Foundation for Social Services], 2004**).** We have to note that our definition of erroneous calls could not be more specific at this point because the data presented in the figure, and which motivated our research, was collected without enough details to allow us to know more about the origin and/or purpose of those erroneous calls. It should be noted also that the teleoperators have mentioned to us that sometimes they perceive users call by pressing any button when they just want to talk to someone. Therefore, the high number of the erroneous calls might also include those originated by loneliness. However, our research, because of the existence of misdirected calls, was designed based on the hypothesis that some errors could have a cognitive explanation.

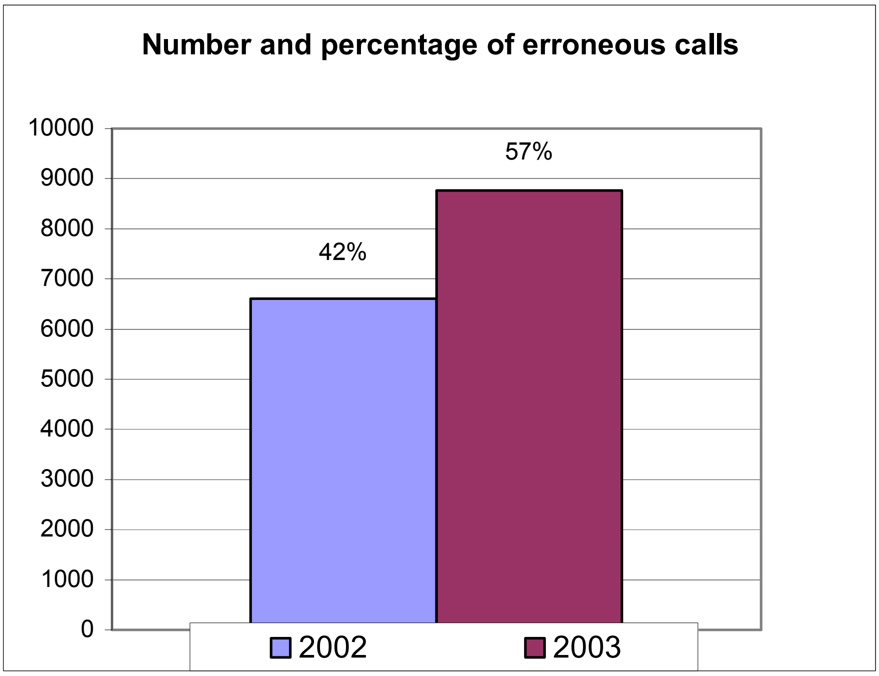

Figure 3. Percentage and number of erroneous calls throughout in 2002 and 2003, at the Andalusia Service of Telecare, Spain.

As we can observe, there was an increase in the number of erroneous calls from 2002 to 2003. In 2002 the calls by error constituted 42% (6,607 of a total 15,375) of the calls that took place in the Center of Attention at the Andalusia Service of Telecare, and in 2003 those errors rose to 57% (8,769 calls of a total of 15,376). The problem this presents is that although the caller called in error, there is always the possibility that it is an emergency call, and perhaps resources are expended unnecessarily. For example, since the same operators handle all incoming calls, they may be busy with an error call when a legitimate call is not being addressed. They might also allocate resources (i.e., ambulances) automatically to attend those error calls, and those resources could be needed to attend to other users. These data reflect a situation that must be addressed by considering how telecare is designed from the point of view of human-machine interaction.

The telecare systems today are designed according to the principle of universal design. According to Ron Mace (2006), *universal design*, also known as *design for all*, can be defined as "the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design" (¶1). According to Seminario Iberoamericano sobre Discapacidad y Accesibilidad en la Red ([SIDAR] Ibero-American Seminar on Disability and Accessibility on the Net, 2006), universal design is based on seven principles. The design must (a) be useful and valid for the diversity of people, and provide the same forms of use for all the users; (b) be flexible and accommodate the diversity of preferences and individual abilities; (c) be simple and intuitive; (d) communicate effectively the information that the user needs, considering the environmental conditions or the sensorial capacities of the user; (e) have tolerance for error, and diminish the negative consequences of involuntary and accidental actions; (f) demand little physical effort; and (g) have size and space accessible for using the device functions easily.

Apparently these principles, which were implemented in the Andalusia Service of Telecare, are not enough since erroneous calls continue. Therefore, we feel that research is needed to find design solutions to reduce the number of errors that the users of this system commit. And we believe that the solutions of design should be based on the analysis of the cognitive characteristics of users. This analysis has to be done within a psychological framework.

The Principle of Mutual Dependency

Cañas, Salmerón, and Fajardo (2005) have proposed a method for analyzing user interaction with artifacts. The method is based on the *principle of mutual dependency,* which states that the human cognitive functions implied in the task will depend on the functions that are present in the interface and that the functions of the interface that help in performing a task will be those that are more appropriate to the human cognitive functions that are implied in the task. For example, the appropriate interface functions will be those that correspond to the structure and function of the human working memory.

Therefore, according to this principle of mutual dependency, designers should consider that any modification, substitution, or introduction of a new function in the interface will result in a change in the human cognitive functions that intervene in the task. In addition, anything that is particular or constraining in the characteristics of the human cognitive functions that are present in some or in all users will set a limitation on the possible functions that are included in the interface. For example, users that have some limitations in their working memory functions would require interface functions that overlook or compensate for these limitations.

So, in summary, the concept of mutual dependency means that

(a) The functions of the interface that are optimal for performing a task will be those that are more adapted to the human cognitive functions that are implied in the task.
(b) The human cognitive functions implied in the task will depend on the functions that are present in the interface.
(c) Any modification, substitution, or introduction of a function in the interface will imply a change in the human cognitive functions of the users.
(d) Any limitation in the characteristics of the human cognitive functions present in any or all of the users will imply limitations in the possible functions included in the interface.

The conceptual framework behind this principle is related to work being done by researchers around the world. For example, at the Center for Research and Education on Aging and Technology Enhancement (CREATE), in Florida, USA, research based on the principle of person-technology congruity is being conducted. The focus is to understand how older users' sensory/perceptual, cognitive, and psychomotor capabilities fit to the demands of new technologies designed for them (Czaja, Sharit, Charness, Fisk, & Rogers, 2001). Their principle of person-technology congruity is quite similar to our principle of mutual dependency.

Therefore, in line with the principle of mutual dependency, we began our research by analyzing the cognitive functioning of the users of telecare systems as the first step in finding solutions to the number of erroneous calls.

Deterioration of Elderly Cognitive Functioning

Different cognitive functions deteriorate with age. (For a recent review of this topic, see Fisk, Rogers, Charness, Czaja, & Sharit, 2004.) Visual functions start deteriorating at around age 40 (D. W. Kline & Scialfa, 1996). But the important problems appear around the age of 60, when people show a reduction of their field of vision, which means a stimulus must be in the center of their field of vision to be detected (Cerella, 1985). Hearing also diminishes with age. Around 20% is lost between the ages of 45 and 54 years, reaching 75% between 75 and 79 years of age (Fozard, 1990; D. W. Kline & Scialfa, 1996). Feldman and Reger (1967) found that people 80 years old miss about 25% of the words during conversations. In general, they are unable to follow a conversation in a group of people when everybody speaks at the same time, and this worsens in stressful situations (Corso, 1977). Speech deteriorates due to either a reduction in motor control or to a loss of the ability to listen to oneself or to others. Therefore, the ability to produce words declines with time, even as the time necessary to produce a word increases (Mackay & Abrams, 1996).

With age, response time in complex motor tasks gets longer (Light & Spiriduso, 1990; Spiriduso & Macrae, 1990). Elderly people show a smaller capacity to perform repetitive tasks that demand great speed, although with enough training they can deal with tasks like striking quickly with a finger (Krampe & Ericsson, 1996). Other evidence suggests that the decline that takes place in the accomplishment of tasks can be compensated for with advanced planning (Welford, 1985).

Attention is also affected by age. Vercruyssen (1996) indicated that elderly people have problems maintaining their attention for long periods of time. This author also suggested (p. 66) that tasks requiring fast and continuing searches are particularly tiring for them. With regard to selective attention, the ability to maintain the attention in the presence of distracters diminishes with age (Conelly & Hasher, 1993). Kane, Hasher, Stoltzfus, Zacks, and Connelly (1995) suggested that this happens because the elderly lose the capacity to inhibit responses to distracting items.

There is an impairment of episodic and procedural memory (Howard & Howard, 1996). This impairment is also observed in the semantic memory but it does not become important until an advanced age. Some studies show a small deficit in the ability to recognize simple, familiar items in tasks of (previously exposed) memory, but there is a significant deficit in the contents of the memory (Hoyer & Rybash, 1992). When the learning material contains histories, text, or interviews, this deficit also occurs in the recognition of significant forms (Hertzog & Rogers, 1989; Hultsch, Masson, & Small, 1991; Stine & Wingfield, 1987). On the other hand, the memory of diverse movements of the fingers that are involved in the verbal memory and/or the memory of motor sequences does not show deterioration with the age (Rybash, Roodin, & Hoyer, 1995). However, as indicated by Krampe and Ericsson (1996), a great amount of practice is necessary to maintain the ability at an expert level, as is the case of the better piano players.

Therefore, as this short review reveals, there are many cognitive functions that deteriorate with age that could explain the high number of erroneous calls. However, we want to address just one of them in this paper: The difficulty that elderly people have when processing language. Older adults maintain and could even improve knowledge of words and word meanings (cognitively), but they suffer deficits in the ability to produce the spoken and/or written forms of words (Burke & Shafto, 2004). They show problems producing well-known words. It has been suggested that older adults´ language abilities are affected by working memory limitations on the production of complex syntactic constructions (Kemper, Kynette, Rash, Sprott, & O'Brien, 1989). That would indicate that these limitations are ones of retrieval rather than comprehension. This phenomenon is related to the well-established distinction between *knowing* and *remembering* that explains phenomena such as the so-called *feeling of knowing* and *tip-of-the-tongue* (Koriat, 1998). Both phenomena could be interpreted by saying that you know something but you can not retrieve it. However, it could be also a problem of word recognition. According to Nelson's semantic-sensorial model (Nelson & Reed, 1976; Nelson, Reed, & Walling, 1976), words have an indirect access to meaning. When reading a word you have to go through a lexical process to recognize letter, phonemes, and so forth, before you access its meaning. On the contrary, pictures have direct access to meaning. Therefore, the language deterioration showed by elderly people could be due to both word recognition and retrieval. And if language deterioration is a factor for the telecare users, then that could explain the erroneous calls. The user interface of the telecare terminals provides labels in words only to indicate the function of each button: If the user is having difficulty with word retrieval, then she/he would have difficulty selecting the appropriate button to press for service.

There could be a simple design solution based on the fact that empirical research has found that aging does not affect the retention of pictorial stimuli (Rybarczyk, Hart, & Harkins, 1987). In a study conducted by Park, Royal, Dudley, and Morell (1988), picture recognition did not show an age-related decline until a week later. Winograd, Smith, and

Simon (1982) have compared verbal and visual encoding by younger and older subjects to determine whether there would be a picture superiority effect that does not change with age. The Picture Superiority Effect (PSE; pictures are recognized and remembered better than words) has been reported in a great variety of semantic tasks (e.g., Pellegrino, Rosinski, Chiesi, & Siegel, 1977) and episodic tasks (Kinjo & Snodgrass, 2000; Paivio & Csapo, 1973). Winograd et al. (1982) found the PSE in both age groups. The finding of a PSE in older subjects indicated that nonverbal codes can be used effectively by people in all age groups to facilitate memory performance. Rissenberg and Glanzer (1986) tested the hypothesis that the PSE in recall would decrease with age in two experiments with undergraduates, older adults with normal memory for their age, and older adults with significant memory impairment. Although the results showed that the PSE declined with age, it was still present in older adults. Moreover, it could be re-established in older adults with normal memory by instructing them to verbalize overtly during the item presentation.

In the field of human-computer interaction, the well-known icon superiority effect has been demonstrated many times in interface design. For example, Arend, Muthig, and Wandmacher (1987) showed the superiority of icons over verbal commands in six different text editor tasks. Spence and Parr (1991) found that responses were faster with icons in a problem-solving task that required choices among multiple alternatives on several variables. Similar results have been found in traffic research. T. J. Kline, Ghali, and Kline (1990) found that the comprehension of text signs could be affected by visual acuity, which is a common problem among old people.

EXPERIMENTAL COMPARISON BETWEEN ICON AND VERBAL LABELS OF TELECARE FUNCTIONS

Based on the research presented above, our hypothesis was that we can reduce the numbers of errors by using icons to indicate the functions on the device interface instead of words. In order to test this hypothesis, we conducted a study in two phases. First, we surveyed a number of people to determine which icon best represented each element presented on the interface. Then, in an experimental setting with a number of experimental subjects, some of them users of telecare systems and some nonusers, we presented the word and icon versions of those function items to the test subjects, who then had to perform a simulation of a calling task.

Phase One: Icon Selection

The purpose of this phase of our study was to select the icons for the design of the graphical interface. The icons selected in this phase were then compared in the experimental phase with their verbal counterparts.

Participants

A sample of 72 subjects was selected (24 young adults, 24 adults, and 24 elderly adults, with an average age of 46 years) through a stratified sampling with the attributes of age and educative level. Age had three levels: young people (average age = 20 years old, range = 18-24 years), 24 adults (average age = 36 years old, range = 25-55 years) and 24 elderly adults (average age = 72 years, range = 56-92 years). All groups contained participants in equal numbers (25% each) possessing one of four educational levels: without primary studies, completed primary studies, completed secondary studies, and completed university studies. All subjects were native speakers of Spanish, the language of the testing.

Materials and Instrumentation

We selected four functions that could be found on the most popular telecare devices: *Familia* [Family], *Emergencia* [Emergency], *Averias* [Failures], and *Información* [Information]. The function Family is used when the user wants to contact a member of her/his family. Emergency means that something is happening (e.g., some medical problem) that needs urgent attention. The function Failures relates to any problem with some home equipment (e.g., the refrigerator is not working). Finally, Information is used for getting some information about anything that interests the user (e.g., name and address of a doctor). All users of telecare devices are familiar with these categories. These functions are listed on the standard devices, but users can change them to any other function labels they like more.

Then we selected six icons for each of the functions from *The Handbook of Pictorial Symbols* (Rudolfh & William, 1974) that contains a collection of 3,250 icons. The icons were presented in a computer display by software developed in visual BASIC 6.0 especially for this study.

Procedure

At the beginning of the session, participants answered a set of questions regarding demographic data, such as age, gender, educational level, type and percentage of disability, and so forth. Percentage of disability is a measure used by the Spanish Administration to assign public resources to people with disabilities; it is assigned by a committee of professionals (medical doctors, psychologists, social workers, etc.). However, it should be noted that the measure includes not only the medical and psychological condition of the person, but also some social variables.

Then, we presented the participants with a booklet with forms in which the concepts for the functions were presented. The participants were to select one icon from the six options that best represented each function's concept. We must note that since this study was done in Spanish, it is possible that people in different cultures might select a different icon for the same word concept.

Results

We calculated the percentage of times that each of the six icons was selected for each interface element. Figure 4 shows the percentage of choices for the six icons for the interface elements. For example, for the concept Family, 55% of the participants chose icon number 6.

The selected icons for each interface element can be seen in Figure 5. The icons that we selected for the experimental phase of the study were those that were chosen by the significant majority of the people.

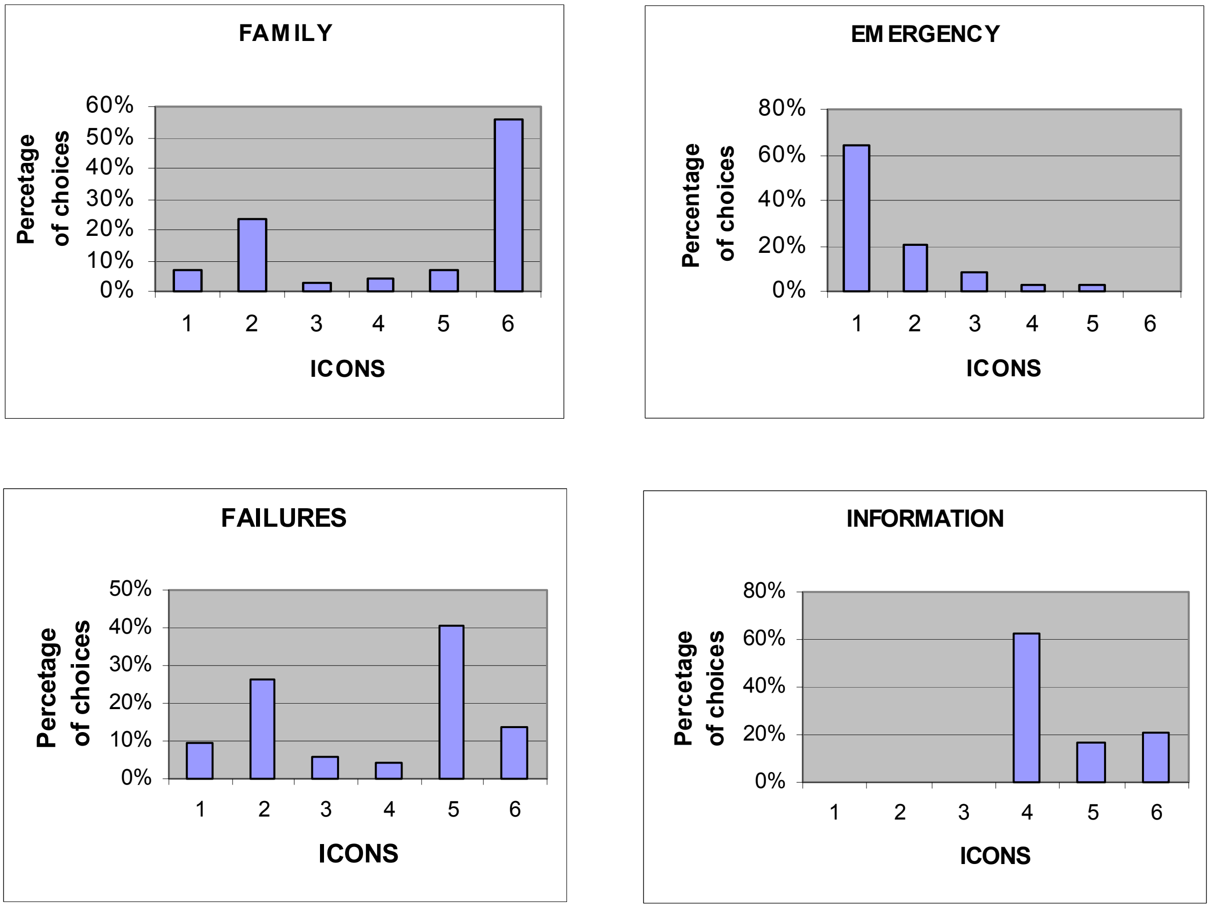

Figure 4. Percentage of choices for the six icons for the interface element.

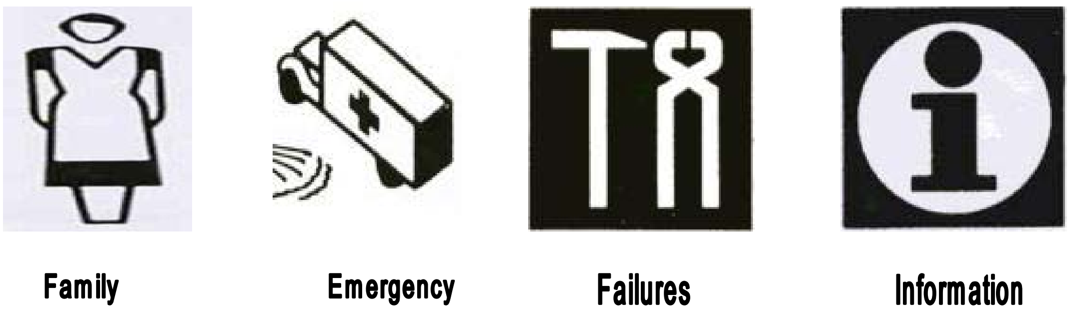

Figure 5. Selected icons for each interface element.

Phase Two: Testing the Icons

The second phase of our study was conducted to test the reliability of the icons in facilitating accurate use of the functions on the telecare interface. In this phase we compared the icons selected in the first phase to their corresponding word labels.

Participants

One hundred and twenty people participated in the experiment. Sixty of them were users of the Andalusian Telecare Service, with an average age of 76 years. The other 60 participants were nonuser control subjects, matched to the experimental telecare users on education level, gender, percentage of disability, and age. All participants were native Spanish speakers; the testing was conducted in Spanish.

Materials and Instrumentation

The stimuli were the four concepts used in the previous phase: Family, Emergency, Failures, and Information. Each icon and its corresponding verbal format were presented separately on a computer screen by the software designed to run this experiment. Due to the lack of personnel and the equipment in our laboratory to design new devices, it was not possible to use modified telecare devices in this study.

Procedure

The experimental session started by asking the participant demographic data about her/himself (age, sex, educational level, and type and percentage of disability). The experimental trials consisted of presenting the four concepts in one of the two possible formats (icon or verbal) depending on the group to which the participant belonged. Both the users and nonusers groups were split into two subgroups, which then performed the task either in the icon condition or the verbal condition. Therefore, there were four groups with 30 participants in each: the User-Graphical condition, the User-Verbal condition, the Nonuser-Graphical condition, and the Nonuser-Verbal condition.

Then a request to call situation was presented in a written format on the computer screen, the subject had to press a key on the computer keyboard to choose the concept (visually or graphically, depending on the subgroup) that would be appropriate for that call. For example, the participant saw a message in the center of the screen saying "Call a family member," which then disappeared and the four concepts (in either the verbal or graphic format) were presented. The concept options remained on the screen until the participant pressed one key with her/his choice.

Only one concept was presented in each trial. Therefore, each participant was involved in four experimental trials plus a practical trial in which a concept not related to the telecare devices was presented. The order of presentation of the four experimental concepts was random and different for each participant.

Design

The design was a 2 x 2 factorial design, with Type of User (User and Nonuser) and Type of Interface (Graphical and Verbal) as the between-subjects factors. The dependent variable was number of errors. Response time was discarded as a dependent variable since it involved the motor ability of the user, which evidently could be different for both type of participants, since the two groups were not matched on motor ability.

Results

Figure 6 shows the results of this experimental phase. We performed an analysis of the covariance on the data with Type of Interface (Graphical or Verbal) and Type of User (User or Nonuser) as independent variables, and Gender and Educational Level as covariates. The dependent variable was the number of errors.

There was no main effect of Type of User, but Type of Interface showed a significant effect, F (1, 119) = 10.72, MSE = 3.00. On the other hand, the interaction was close to significance, F (1, 119) = 3.40, MSE = 0.95, $p < .07$. An analysis of the simple effects showed that the differences between users in the condition of Verbal Interface were significant, F (1, 114) = 10.72, MSE = 0.28, p < .01, whereas the differences in the condition of Graphical Interface were not, F (1, 114) = 3.29, MSE = 0.28, p = 0.7.

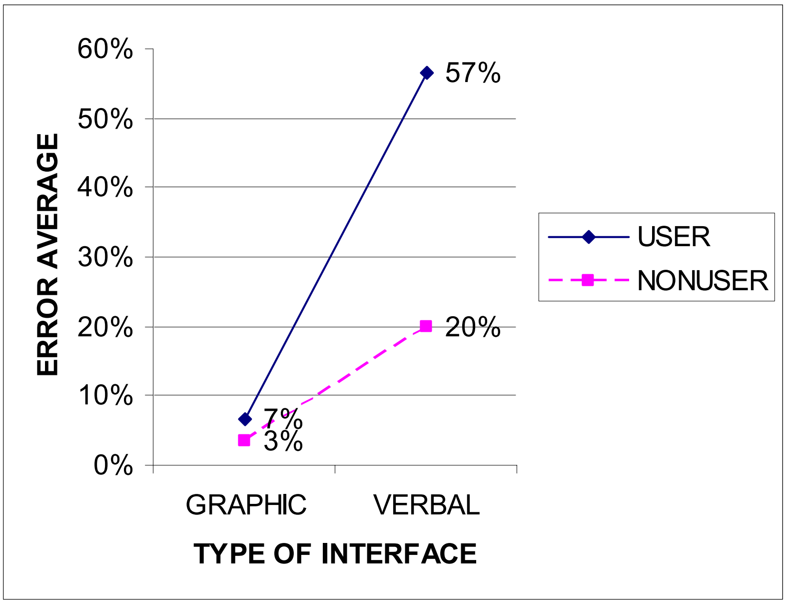

Figure 6. Error average for users and nonusers of Telecare systems.

Discussion

The results of the experimental phase show clearly that a possible cause of the calls in error observed in a telecare services could be due to the exclusive verbal design of the current telecare interfaces. The comparisons between the performances of users and nonusers with both interfaces revealed two important issues. In the first place, for both types of users, the Graphical Interface reduced the number of errors. Second, and more important, the differences in the number of errors that were observed between both types of users were reduced enormously with the Graphical Interface. In other words, users committed significantly more errors than the nonusers with the Verbal Interface, whereas the number of committed errors was very similar among participants with the Graphical Interface.

We can interpret these results within Paivio's (1991) dual coding theory. People commit fewer errors with a graphical interface because they understand the meaning of the buttons better than with a verbal interface. Meaning is better accessed with picture than with words and both types of cognitive representations (visual and verbal) of the icons allow an even better access to meaning. Accessing the meaning of words alone is more confused because words have just one cognitive representation (verbal).

However, other models could also explain these results. For example, Nelson's semantic-sensorial model (Nelson & Reed, 1976; Nelson, Reed, & Walling, 1976) would predict that people commit fewer errors with the graphical interface because the visual characteristics of icons are more distinguishing than those of words and the access to their meaning is direct. To access the meaning of words it is necessary to process their visual and phonetic characteristics.

GENERAL CONCLUSIONS

The main conclusion that could be reached from the results of this experiment is that the principle of universal design must be complemented by an analysis of the cognitive functioning of the users if we want to improve telecare system design. Although we have only tested a single hypothesis that refers to the graphical or verbal characteristics of the interface, we found results that could point to an important cause of erroneous calls. Therefore, it seems reasonable that if we look deep into the cognitive analysis of user interaction with telecare systems, as suggested by the principle of mutual dependency, we should be able to find other potentially important variables. This analysis could be based on empirical research done in cognitive psychology with elderly people, as well as with cognitive theories, such as Shallice and Cooper's (2000) theory that has been developed to explain the erroneous conduct of people. In practical terms, we must say that this research will solve an important economical problem at the Telecare Services, since erroneous calls mean an important loss of resources.

It is important to note also that although there could be other possible noncognitive explanations (e.g., accidental physical pressure on the telecare device) for the large number of erroneous calls observed by telecare providers, the cognitive functioning of elderly people may also play a significant role in this scenario. Therefore, we believe that it is worth the effort to explore hypotheses based on the analysis of the cognitive functioning of elderly people.

Finally, it is also important to say that a possible flaw in our experimental design was that we did not make any evaluation of the cognitive ability of our participants. Therefore, even if the participant were matched on four control variables (educative level, gender, percentage of disability, and age), the participants in the User group could be more cognitive deteriorated than participants in the Nonuser group. The participants in the User group were people that had requested the installation of telecare devices, and that could mean that they are less able to live by themselves.

The only criterion related to cognitive ability that we could have used to judge cognitive ability was the percentage of disability, but it comprises medical, psychological, and social variables. However, the Andalusian Service of Telecare requires that potential users have a minimum of psychophysical conditions to operate the device. It could be interesting to repeat this study with some assessment of the participants' cognitive ability to test this factor's effect more appropriately.

ENDNOTE

1. Although all new units of telecare devices delivered to clients contain specific terminology related to call destinations at the telecare service center as the speed dial options, clients are free to rename or alter this terminology for their convenience. This unit shows the speed dial options preferred by a particular user.

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DESIGN OF A VIRTUAL LEARNING ENVIRONMENT FOR STUDENTS WITH SPECIAL NEEDS

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Abstract: *The European Social Fund-supported Portland Partnership project developed a computer-based virtual learning environment (VLE) to benefit students with cognitive and physical disabilities. This system provided students with access to a suite of software programs to teach them basic/essential skills needed for everyday life and to use information and communications technology (ICT). The VLE can be customized to meet individual students' needs by selecting an input device, adjusting its setting, or choosing a symbol set to support on-screen text. The learning programs within the VLE required careful design to make them stimulating and beneficial to students who have diverse health conditions and disabilities. The VLE and learning programs were evaluated within four partner Colleges of Further Education. Observations showed that students enjoyed the learning tools and the tutor comments indicated that students also benefited from them. A series of guidelines were identified for the design of future VLEs and learning software for students with special needs.*

Keywords: *virtual learning environment, learning programs, special needs, physical and cognitive disabilities, human-computer interaction.*

INTRODUCTION

Students with severe disabilities and special needs may suffer from a wide range of communication and learning impairments. A physical disability such as cerebral palsy or muscular dystrophy can affect a student's ability to form words. A cognitive disability such as autism affects the way a person communicates and relates to others around them. Students with down's syndrome may have multiple disabilities affecting both their thinking processes

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and their ability to vocalize. The use of speech by these students may be limited and verbal utterances are likely to be supplemented by gestures, facial expressions, and pointing. Such students are often unable to read and may work with special symbols.

Symbols have been used for many years by people who have communication difficulties to improve their access to information and as a means of supporting conversation. Symbols differ from pictures in that each symbol represents a single concept. Two examples (see Figure 1) of these symbolic systems are the Widgit Rebus Symbols, currently containing 7,000 items covering a vocabulary of over 20,000 words (Widget Software, n.d.), and Mayer-Johnson's Pictorial Communication System (PCS), containing 10,000 items (Mayer-Johnson, n.d.).

Examples of learners (using pseudonyms) addressed by this paper include Jenny, an 18-year-old student who has cerebral palsy and limited verbal communication. She is at the Pre-entry level of learning (see the Appendix). She also uses a wheelchair. She is nervous about computers and has little experience with them. She uses a large button (called a switch; see later section, Switches and Assistive Technology) to operate a program on a computer but will not look at the screen. Chris is 21, has autism, and often lapses into nonverbal communication. He can use a switch to control a computer and has become an enthusiastic computer user. He is at the Entry 1 level of learning. Mark is an 18-year-old student with down's syndrome. He can communicate quite well, can use a mouse, and has a good deal of experience with computers, since he has one at home. He is at the Entry 2 level of learning.

For students such as these, learning is at a basic level and so, as young people and adults working at the eight Pre-entry milestones of the UK Adult Core Curricula, they are taught basic/essential skills in literacy, numeracy, and communication, as well as skills for daily life, such as washing, dressing, and cooking. Students who are a little more advanced are at the Entry 1 and 2 levels, with the broader aims of building their literacy and numeracy skills, increasing their level of independence, and possibly taking up some form of employment. The Appendix summarizes the framework for the UK Adult Core Curricula for learning literacy and numeracy for adults with learning difficulties and/or physical disabilities addressed by this paper. The complete documents for the Pre-entry Adult curriculum in the UK are published jointly by the Department for Education and Skills and the Learning and Skills Development Agency (DfES & LSDA, 2002).

Computer-based programs can support teaching by offering cognitively and physically challenged learners stimulating activities, staged learning appropriate for their ages and cognitive levels, and resources enabling them to work creatively. The use of facilities such as the Web and e-mail, which mainstream students use all the time, also increases their self-esteem. While stand-alone computer-based learning programs have been around for a long time, integrating them into a virtual learning environment (VLE) offers significant advantages.

Figure 1. Examples of PCS and Rebus symbols.

Stiles (2005, ¶ 5) describes VLEs as "on-line systems that provide collaborative interaction between tutors and students, and between students as peers, while also providing asynchronous learning resources for individualized use by students at any time." Students will normally access the system using an ID and password. Once connected, they can communicate with their tutors and peers, view their timetable and course materials, work on projects in small groups, and access wider reference materials. A VLE can support the specific needs of students in terms of how the learning programs are presented and controlled. For example, voice output may be introduced to read aloud instructions for the student, or scanning options can be selected for switch users. The VLE may also be flexible enough to allow installation of various learning programs from different suppliers.

This paper reports on the work of the European Social Fund's (ESF) Portland Partnership project (2005), which developed a computer-based VLE to support learners with severe learning and communication disabilities. The specific aims of the Portland Partnership are

- to develop a VLE and learning content to help students (or "beneficiaries" in ESF terms) develop skills in computer use, such as understanding cause and effect, navigation through software, and mouse functions (e.g., click and rollover);
- to give learners a greater degree of autonomy in terms of logging in, interaction with a personal computer (PC), and e-mail;
- to provide access for any learner, irrespective of the severity of his/her physical and/or cognitive disability, to the national framework for basic/essential social and self-care skills and to encourage learner progress through clearly structured and optimally accessible tools and materials; and
- to provide appropriate materials to help learners at the Pre-Entry level and above develop the relevant skills that may provide greater access to employment.

The project, which was a collaborative activity between partner organizations, was coordinated by Portland College in Nottinghamshire, a day and residential college that specializes in teaching students with physical and/or learning difficulties. Three Colleges of Further Education—West Nottinghamshire College, North Nottinghamshire College, and Chesterfield College—acted as test beds for the VLE, along with Portland College. The VLE itself was produced by Teesside University, while the learning materials were created by the Cambridge Training and Development Limited (CTAD). Two universities, Nottingham Trent University and the University of Nottingham, jointly developed a prototype wireless switch input device for students to use (described in a later section). The role of the authors' organization, the Ergonomics and Safety Research Institute (ESRI), at Loughborough University, was to perform a user-based evaluation of the VLE and learning programs within the four test bed colleges (Portland, West Nottinghamshire, North Nottinghamshire, and Chesterfield). This paper reports on the evaluation work carried out by ESRI and the results obtained. The study involved students with a wide range of physical and cognitive disabilities who are attending ICT classes in the colleges.

The next section provides a literature review on VLE accessibility and usability. This is followed by a description of the method employed to evaluate the VLE and learning programs and the results obtained. From the results, a range of design guidelines are identified for the design of interactive learning tools for students with complex disabilities. This is followed by a sample of tutor comments illustrating students' progress after using the learning tools developed within the project. The paper concludes with an overview of the main findings from the study and ideas proposed for future learning program enhancements.

VLE DESIGN AND EVALUATION PRINCIPLES

VLEs are now widely used to support learning within further and higher education institutions[1] (Dunn, 2003). This has stimulated research in the area of designing such systems for users with special needs. The focus of this literature review is therefore on the design of VLEs and teaching materials for students with severe physical and/or cognitive disabilities that affect both their communication and learning processes.

Accessibility Issues

Accessibility is the ability of a product or system to be perceived and used by people with the widest range of capabilities. To support accessibility, the system should be flexible so that it can be adapted to people with specific needs. For example, it may allow the text size and contrast between the text and background to be increased to meet the needs of users with visual impairments. Accessible systems also allow a connection to assistive technology for disabled users, such as a screen reader, speech input device, or switches for users who require a very simple method of input. (For more information see Gill, 2004, 2006; the World Wide Web Consortium's Web Accessibility Initiative [W3C–WAI], 2005; the legislative requirements of Section 508, enacted in 1998, of the United States Rehabilitation Act, n.d.; and the mandatory accessibility of learning materials in the UK, enacted by the Special Educational Needs and Disability Act [SENDA], 2001.)

Stiles (2005) conducted a study to record problems encountered by disabled students of two VLEs and then identified possible solutions. Stiles found that navigating a VLE posed the most problems. He suggested a number of guidelines for designing accessible navigation, many of which are based on the W3C's Web Content Accessibility Guidelines (W3C–WAI, 2006b). A few of the example guidelines, from Stiles (2005, section 5.1.1), relevant to students with special needs are presented here:

- Make it easy for the user to control the "focus" of the screen, that is, the part that is currently active (highlighted by the cursor) and to ensure that this is in sync with the assistive software providing audio support.
- Keyboard equivalents for all menus and menu options must be provided.
- Keyboard accelerators (shortcuts) should be available where tabbing becomes excessive.
- Allow the user (tutor or learner) of the VLE to override settings, such as font style, size, and color, and the background color of the screen, possibly through Cascading Style Sheets (CCS).
- The use of icons must be accompanied by textual information or alternative text that can be accessed via screen reading software.
- Ensure that, in addition to the VLE, the learning content within it is also accessible.

The EU's World Wide Augmentative and Alternative Communication project (WWAAC, n.d.) developed an adapted Web browser tailored to the needs of users with complex communication and/or cognitive impairments. It also developed a communication infrastructure and protocol to support symbol-based communication based on concept coding that is used by many Augmentative and Alternative Communication (AAC) users. An example of the WWAAC browser screen showing simplified command icons and links to predefined user favorites pages is shown in Figure 2.

The WWAAC project evaluated their adapted browser with users with positive results. The users' experiences were affected however by external factors, such as the browser leading to poorly designed Web sites (a problem also found by Stiles), and technical problems, particularly with the scanning process for switch input devices. The project concluded that Web developers and designers should be provided with guidelines and standards for accessible design for people with a range of communication disabilities. Practical accessibility guidelines for Web masters have been suggested by the WWAAC project, based on the project's user requirements and evaluation work (Poulson & Nicolle, 2004). These guidelines have been fed into the W3C's WCAG Working Group (W3C–WAI, 2006a) and can be found on the WWACC project website (WWAAC, n.d.).

While accessibility for a wide range of users is an important requirement, this may be difficult to achieve. As Techdis (n.d.a, ¶1) states, "Accessibility is often a balance between contrary tensions. A text-based resource accessible to screen readers [for users with visual impairments] may be inaccessible to a dyslexic learner, a deaf learner or somebody with cognitive difficulties." Techdis (n.d.b) further emphasizes that "Providing responsive pedagogical solutions is often more important and effective than making something 'technically accessible' [to a screen reader]" (Personal reflections section, ¶1). In terms of accessibility then, Pre-entry learners with severe physical and/or cognitive disabilities require facilities that match their particular capabilities and needs, such as bright animated content with speech output, together with very simple methods of input and navigation.

Figure 2. WWAAC project browser screen showing a Favorites page.

Usability Issues

Usability is concerned with the ability of the users to understand the system, navigate through it, and achieve tasks with few errors. According to authors such as Dix, Finlay, Abowd, and Beale (2003), Nielsen (1994), and Rogers, Sharp, and Preece (2002), a usable design should be

- simple and intuitive
- consistent with conventions or standards
- flexible and efficient
- clear in prompting and giving feedback
- helpful to the user in avoiding errors as well as supporting error recovery.

Dunn (2003) conducted a study aimed principally at people involved with the implementation of VLEs in further and higher education institutions. She conducted six interviews with educational specialists within UK universities and a college of higher education, had email exchanges with experts in the field, and performed an online survey of users of academic mailing lists run by the Joint Information Systems Committee, gathering 46 responses. Many respondents commented on the difficulty that users with disabilities had in using a VLE, even if it was technically accessible. Problems included too many windows, poor keystroke navigation, and unclear help messages. Dunn also found that learner competencies may be overestimated by both tutors and the learners themselves. Assessment and support strategies are needed to address these issues, otherwise this could lead to a reduced quality of learning experience, loss of confidence, and a reluctance to engage in further learning experiences via the VLE by students with disabilities.

Barnes and Walter (2000) provide advice on designing Web pages for people with learning and communication difficulties that could be applied to VLEs and to learning software in general. They propose using large clear buttons that incorporate icons as well as text. They also suggest using consistent and clear page layouts, avoiding complex backgrounds (a simple white background is sufficient), avoiding the use of scrolling pages, providing symbol support for plain text, and placing navigation controls in a consistent place on the screen. These guidelines have been applied to the Portland Partnership VLE and the learning software to make them as usable as possible.

Personalization

Personalization of software allows it to be customized to the user's requirements and preferences, initiated either by the user or by the computer. A fundamental limitation of e-learning systems is that they give students little opportunity to influence and manage their learning activities (e.g., control the order of learning, tailor the problems to their own situations), which are important for knowledge construction (Martinez, 2002). For students with learning and communication disabilities, it is important for the system to be adapted to their specific needs, such as their choice of input device or symbol set. It is also desirable to allow the students to make choices about which learning programs they use. In the Portland Partnership work, an important element was the ability to tailor the software inputs and outputs to the needs of the individual users. Consideration was also given to allowing residential students and students staying after normal teaching hours to choose which learning activity they would undertake in the evening and to record it on their VLE timetable.

Multimedia and Multimodal Techniques

There is much evidence to support the benefits of using of multimedia and multimodal interfaces for students with communication and learning disabilities. Itoh (2002), for instance, reports that people with autism have good visual information processing skills and that AAC systems with graphic symbols have been used successfully with autistic children at special schools. In the Portland Partnership, the programs were visual in nature and symbols were used for activities such as login and navigation. Schlosser, Belfiore, Nigam, Blischak, and Hetzroni (1995) have shown that speech output communication devices facilitate graphic symbol learning, while Burkhart (2002) found that multimodality (e.g., mouse and switch input with audio, text, and graphic output) can support children with autism by enhancing receptive understanding, cognitive processing, and expressive language; reducing frustration; and improving behavior.

Switches and Assistive Technology

Many users with physical or cognitive/learning impairments have to use a switch rather than a keyboard or mouse to interact with software. A switch is a simple button used with software that presents a scanning rectangle on the screen. The user presses the switch when the rectangle is located on the selectable item they want, such as a menu option, picture, or on-screen button. This may then lead to more options to select in continuing the interaction. Usually the rectangle moves automatically (autoscans) with a single switch used for selection. Alternatively, the user may operate two switches—one to tab between items on screen and another to make the selection. The first method is the most efficient for users who have developed good timing skills and it should be possible to change the scan speed to suit the user. Two switch scanning gives more control to the user but demands physical access to, and reliable control of, both switches (Colven & Lysley, 2001). Figure 3 shows a pair of switches that can be linked to a PC.

Within the Portland Partnership, Nottingham Trent University and the University of Nottingham developed a prototype wireless switch (Brown, Battersby, Standen, & Anderton, in press) making it more convenient for a student to use the VLE, particularly in conjunction with other assistive technologies that they may require. The switch can store information about the student, which is then communicated to the VLE so that the system can be customized to meet his/her cognitive and physical needs. Potentially the switch could contain the user's login details

Figure 3. Switches with a PC interface box.

for the VLE, preferred scan speed, text size, screen colors, and so forth. A simple game program was developed by the same partners to test the user's responsiveness so that the scan speed of the switch could be adapted to the current physical state of the student and his/her level of alertness or fatigue.

Another issue is how well the communication aids that disabled students may use for everyday communication fit in with the PC they use to access the VLE and the learning programs. Students with complex communication problems may need to use a speech synthesizer with a special keypad, or special switches attached to their wheelchair, to communicate with others. Users with such needs therefore require that their communication aid is compatible with the VLE computer and that they can physically reach the system (Poulson & Nicolle, 2004).

Curriculum Basis and Progression

Sturm (2002) emphasizes the importance of relating learning programs for special needs to the curriculum for the students. She states, "A solid understanding of grade level curricular demands, literacy activities, and materials used will allow school support teams to consider individual learning needs and develop appropriate activities" (p. 1). A progressive curriculum for both schools and adult education may be based around a framework such as

- switch access
- passive stimulus (e.g., video sequences)
- cause and effect, and coordination
- pre-academics (e.g., choice making, matching, sorting, life skills)
- academics (i.e., numeracy and literacy skills).

The Portland Partnership produced learning software within a similar framework for students at the Pre-entry and Entry levels.

Evaluation of Systems with Special Needs Users

Useful guidelines for running user evaluations with special needs students are offered by Heim, Endestad, Skjetne, Maguire, and Vereker (1998). They state that it is important that a user with cognitive impairments feels safe and secure and therefore should be accompanied by someone he/she knows, such as a tutor or assistant (caregiver). The evaluator may interact with the student, with or without the tutor assisting, or be present in the background. The aim of the test must be clearly and simply stated to put the user at ease.

Students with cognitive impairments prefer to learn new things slowly, in a step-by-step fashion. Therefore, they should be given enough time to complete each program and to overcome any problems that arise. It is important not to put too much pressure on users to complete the tasks, and to provide support when needed. For students with physical impairments it is necessary to consider whether the physical arrangement of the desk and chair is suited to the user, and whether users in wheelchairs can reach the input device, particularly if they have communication aids or other devices attached to their wheelchair.

The user should be assessed to determine the most suitable input device for him/her. These input devices include, for example, a mouse, single switch, dual switch, or large keyboard. The student's preference for input device should also be considered. For both cognitively and physically impaired students, each user session should be kept short to prevent the students from becoming tired and losing concentration. In addition, having shorter sessions enables several students to take part during the same classroom period.

In order to capture user assessments of learning software from users with cognitive impairments, a simplified rating scale is needed. Murphy (1998) developed a low-tech tool called Talking Mats to assist in communicating with AAC users. Three sets of picture symbols representing issues, emotions, and influences were arranged on a textured mat to create a composite picture of what was meant. The Talking Mats are intended to supplement a person's means of communication rather than replace his/her communication aid or use of facial expression and gesture. In Murphy's (1998) study, the Talking Mats were used with people with cerebral palsy and expressive dysphasia. This idea was also used within the WWAAC project to gather user attitude data as reported in the user evaluation plan (Nicolle, et al., 2004). A similar type of smiley scale was used successfully in the Portland Partnership project, as described in the Evaluation Method section of this paper.

VLE and Content Design

The main focus of the development team was to produce a VLE with learning content accessible to learners from the earliest milestones of the Pre-entry level to Entry Levels 1 and 2 (the Portland Partnership target user group). The problem with many commercial VLEs, however, is that they are pitched at too high a cognitive level and often lack the accessibility features that learners in this group require. The Portland Partnership VLE was therefore designed to focus on the needs of learners with severe cognitive and communication disabilities, that is, to be primarily graphical and audio-based rather text-based, as many of these students respond best to pictures and sounds and are also non-readers. Macromedia Flash and an audio/visual interface were employed to be attractive to Pre-entry learners. The VLE components were supported with symbols, graphics, and audio and speech output to enhance on-screen instructions. The environment could also be customized for individual student's needs, such as an adjustable switch scan speed and the choice of symbol set (PCS or Rebus). The learning materials produced by the Portland Partnership enabled students to develop basic/essential self-care skills and ICT skills simultaneously. As the VLE was aimed primarily at a Pre-entry level, age-appropriate and accessible materials were designed to augment existing learning resources, to reinforce good learning practices, and to help develop skills, such as an awareness of cause and effect, navigation through software, and basic literacy and numeracy. Further details of the VLE and learning materials are provided within the Evaluation Results section of this paper.

EVALUATION METHOD

The Portland Partnership developed its own learning programs and VLE, each of which was evaluated by the authors of this paper in conjunction with the tutors and students in the partner colleges. The method adopted for the evaluation is described below.

Evaluation Aim and Objectives

The main aim of the evaluation was to test the Portland Partnership's software-based learning programs and VLE with a wide range of students with communication difficulties caused by severe cognitive and physical disabilities. The supporting objectives were to

- evaluate the effectiveness of each program or VLE element by making observations of its use by students and recording tutor comments;
- draw out specific recommendations for improving the programs; and
- identify general guidelines for designing learning programs and VLEs for students with cognitive and physical disabilities.

Participants

Initial meetings took place with the tutors at each of the partner colleges in November 2004 to discuss plans for the evaluation and inquire about the various students who could participate. These meetings helped provide profiles of the user subjects, and to discuss the ICT equipment required. Participants were recruited from the Colleges of Further Education within the project (North Nottinghamshire College, West Nottinghamshire College, and Chesterfield College) and the specialist Portland College. Since the students needed to remain within the normal classroom setting supported by tutors or assistants, it was decided to run the evaluation sessions during the periods that the students had ICT lessons. This minimized the disruption to the college timetables.

Student Sample Profile

Across the four colleges, a total of 27 students participated in the evaluation. As Table 1 shows, these students have a wide range of medical conditions (some having multiple conditions) that significantly affect their physical, sensory, and cognitive abilities.

Of the users, 20 are male and 7 are female, and aged between 18 and 24 years, with the exception of one male student who was 54. Regarding input devices, 18 were mouse users, 8 were switch users, and one was a joystick user. In terms of educational level, 18 of the students were at Pre-entry level, while 9 were at Entry 1 or Entry 2 level. Approximately half of the students (14) are wheelchair users. In terms of computer use, 8 were fairly familiar with using computers (within the limits of their capabilities), 12 had some experience in computer use, while 7 had little experience. The majority (17) said they were "enthusiastic" about using computers, while the others were less so.

Informed Consent

It was necessary for each student, or his/her parent or caregiver, to agree to participate in the VLE evaluation trials and to sign an informed consent form. The decision to participate was jointly agreed to by the student and parent. The student then signed the consent form if he/she was able. Otherwise it was signed on his/her behalf by the parent or caregiver. It was later decided within the project that informed consent would be obtained for all project-related user trials as part of a single process.

Table 1. Conditions Represented in User Sample Within the Evaluation.

Condition	Physical	Sensory	Cognitive	Number of students in sample affected
Autism		✓	✓	1
Autism and nonverbal communication		✓	✓	1
Cerebellar hypoplasia	✓			1
Cerebral palsy	✓			1
Cerebral palsy & severe learning difficulties	✓		✓	4
Cerebral palsy and limited or nonverbal communication	✓		✓	4
Cerebral palsy, sclerosis of spine & global developmental delay	✓		✓	1
Down's syndrome	✓	✓	✓	3
Down's syndrome, limited verbal communication and registered blind	✓	✓	✓	1
Dyslexia and learning difficulties			✓	1
Global developmental delay			✓	1
Hemiplegia & auditory defensiveness	✓	✓		1
Leigh's encephalopathy	✓	✓	✓	1
Memory loss (short & long term)			✓	1
Physical injury	✓			1
Soto's syndrome	✓		✓	1
Spina bifida & hydrocephalus	✓		✓	1
Wolf-Hirschhorn syndrome	✓		✓	1
Worster-Drought syndrome	✓			1

Evaluation Tools

A checklist was developed to support the observation of the students. In addition, a rating scale was created to capture student reactions to each learning program or VLE element.

Observation Checklist

To support the evaluation of the VLE software and learning programs, a general checklist was defined regarding aspects to look for when observing students:

- ability of the program to stimulate and maintain the interest of the student;
- ability of the student to navigate and complete the program successfully;
- flexibility of the program to support the individual student's unique needs;
- types of errors made by the student in using the program;
- the time and effort needed by the student to complete the program;
- the student's level of satisfaction having used the program.

Smiley Rating Scale

A version of the smiley rating scale described in the literature review was used to gather students' ratings of satisfaction with each learning program. During a pilot evaluation of the early prototypes, it was found that a 5-point scale could be used successfully. To elicit user responses, the students were shown the smiley scale. The facial expressions on the scale were made distinct in order for the students to easily differentiate them when giving a rating (see Figure 4).

It was thought that the scale could be presented to each student either on the screen of a laptop computer or on a laminated card. It was found to be easier and more flexible to show the scale on a card and to record the ratings, together with the observation notes, on paper.

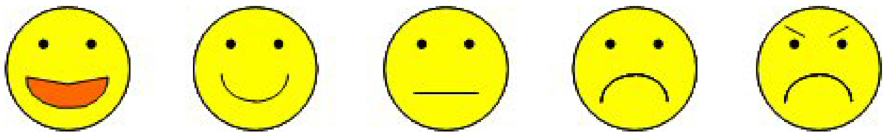

Figure 4. Smiley scale to capture student feedback.

Evaluation Procedure for Each College Visit

The VLE and learning programs were evaluated between February and May 2005, focusing on new programs as they were developed and disseminated to the colleges. Some of these were early prototypes and therefore works in progress. Access to the full VLE was also limited, as project partners were in the process of completing it and integrating the programs within it.

In general, two ESRI evaluators worked with each student, one guiding the student's use of the learning programs, the other recording observations and ratings. Occasionally one evaluator worked with the student, both guiding the session and recording observations. A tutor was also on hand to assist in communication with the student, although this was rarely necessary. The tutors advised the evaluators as to which students should try which programs, based upon their capabilities, and which programs they had not used before or only a few times (and so had not become bored with them). The evaluation was based upon a specific IT student group at each college and so some of the testing of software designed for Pre-entry milestones included feedback from students at the higher Entry levels. However this was still found to be useful. It was intended that each student would spend only a short time at the computer to give him/her a chance to try some programs but not become bored or restless. This approach meant that each student used only a portion of the programs available.

Within each session the following procedure was adopted:

- Before each session started, the tutor gave some background information about the student taking part in the trial—his/her name, age, medical condition or disability, learning level, preferred input device, and any other relevant details (e.g., "may not want to stop using the computer at the end of the session").
- When the student came to the computer, he/she was informed by the tutor or evaluator that he/she would be using it to test some learning programs. The tutor then suggested which programs were suitable for that student's capabilities.

- The student was asked to use three or four programs per session. He/she was given a little help to get started and further help as needed. The students normally worked on each program for about 5 minutes before wanting to try another, making the session 15 to 20 minutes in length.
- While each program was being used, the evaluators made notes of their observations of the student's use of the program.
- When the student finished each program, he/she was asked to give a smiley scale rating to indicate how much he/she enjoyed using it. This seemed to work well as the students were able to point easily to the appropriate face on the scale.
- At the end of each session, the tutor gave some general comments about how well he/she felt the student had done. The tutor also commented on the programs and how they could be enhanced to better meet the student's needs.

EVALUATION RESULTS

This section presents the evaluation results for a representative sample of the learning programs and VLE facilities tested. Since the evaluation, a number of updates have been made to both the VLE and the programs by the project development partners, taking account of the results obtained.

Observations of Students

The learning programs and VLE software that were evaluated are classified into two main categories:

Learning Programs

- video stimulus
- cause and effect
- number, matching and sorting skills
- life skills
- slideshow authoring and presentation.

VLE Facilities

- VLE login
- e-mail
- tutor tools.

The observations made of students using the programs and facilities within each category are presented below. The data presented summarize the reactions of the students as a whole to each program. They describe which parts of the programs the students enjoyed as well as how well they performed, which is an especially important aspect of a successful user experience for students with severe disabilities and special needs.

Video Stimulus

A short video sequence, titled What We Like, showed individual students carrying out creative activities within college sessions and also attending a party. Since the video required only passive viewing, it was appropriate for most of the students. Some viewers were stimulated by recognizing fellow students in the video. Several felt that they would like to be filmed when performing a similar activity and be able to see themselves on screen. Those who did not recognize the students in the video were generally less enthusiastic.

Cause and Effect

This group of programs showed everyday scenes and activities to teach an appreciation of the concept of cause and effect. The users could click on the people and objects in the scene that were then animated using the Flash software. The programs were developed mainly for Pre-entry learners.

Fireworks. This lively program consisted of two parts. First, the user clicked on a moving rocket to make it explode. He/she then clicked on a set of planted fireworks to see a display with sound effects (see Figure 5). This appealed to all of the users and several Pre-entry students found it exciting. They liked the variations presented when clicking on the rocket to make it explode into different colors. However some of the students were unsure what to do when the first screen was displayed. One tutor suggested that the rocket and fuse could be larger or there could be a match or flame to click to start the process. For higher level learners, it was suggested that the program could include added variety, such as having several different fireworks on screen, or allowing the user to select the order in which the pyrotechnics were set off.

Figure 5. The Fireworks program.

Party. This program presented a party scene (see Figure 6) in which users could click on individual partygoers to make them dance, eat, serve drinks, and so on. Students enjoyed using this program when encouraged to click on the different characters. Wheelchair students could identify with the girl and boy who danced in their wheelchairs. They also enjoyed seeing a person opening a door to complain about the noise. The activity was designed for the early milestones of Pre-entry level students to develop an understanding of cause and effect. Therefore, the Entry level students who used it found it slightly basic for them.

Figure 6. The Party program.

Kitchen. Students clicked on kitchen equipment items to animate them and to hear the sounds they make (see Figure 7). Each sequence included a kitchen disaster, such as toast burning, food in the microwave exploding, the washing machine leaking, or water rising in the room with a picture of a shark swimming past. The more advanced students, who appreciated that these events were fictional, enjoyed seeing things going wrong and could identify with the mishaps. However some of the students at earlier stages of learning made a more literal interpretation and became anxious when seeing the disaster elements. It was suggested therefore that a second version of the program be developed, without the disasters, for the Pre-entry students.

Figure 7. The Kitchen program.

Number, Matching and Sorting Skills

This group of programs was designed to teach number and matching skills using well established games, such as pairs, snap, and a slot machine. A program on sorting objects into groups was also included. A cinema theme program required number and matching skills to direct a visitor.

Pairs. In this game, a set of cards was displayed showing different colors to match. An upbeat chime sounded to indicate a correct selection while a downbeat sound (known in the UK as a “raspberry”) was used to indicate an incorrect selection. The students found this latter sound amusing. Some of the project staff anticipated that students might deliberately put in the wrong answer when pairing cards in order to hear it. However, this did not turn out to be a problem or prevent the students from using the program properly. In a variation of the game, the cards contained both analogue and digital times of the day to be paired off, for example, 4 o’clock on a clock face and 4:00 shown as a number. This version was seen as a good way for students to learn to tell time and was enjoyed by most of the users.

Cinema. Here a cinema setting was shown (see Figure 8). Students were given choices such as which studio to enter with their ticket (showing the studio number) and which washroom to go into afterwards (Men’s or Ladies’). This program was enjoyed by Entry level students, especially when a man who was sent into the Ladies’ washroom by mistake reappeared with a red face.

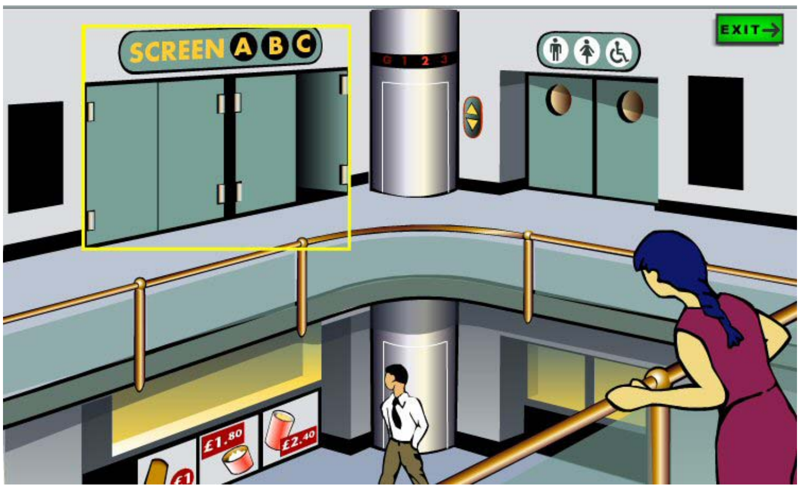

Figure 8. The Cinema program.

Sort It Out! In this program, a sequence of forks and spoons appeared above two drawers. The user was required to identify each one as it appeared and click the correct drawer to place it (see Figure 9). Most of the users liked this program. One student found a “cheat” mechanism: By clicking the mouse quickly on the item, the program automatically put the spoon or fork into the correct drawer. The auditory feedback given for either correct or incorrect selections was found useful by the students. Another student tried to drag and drop items into the draw rather than just clicking on the correct draw and so needed guidance from the evaluator.

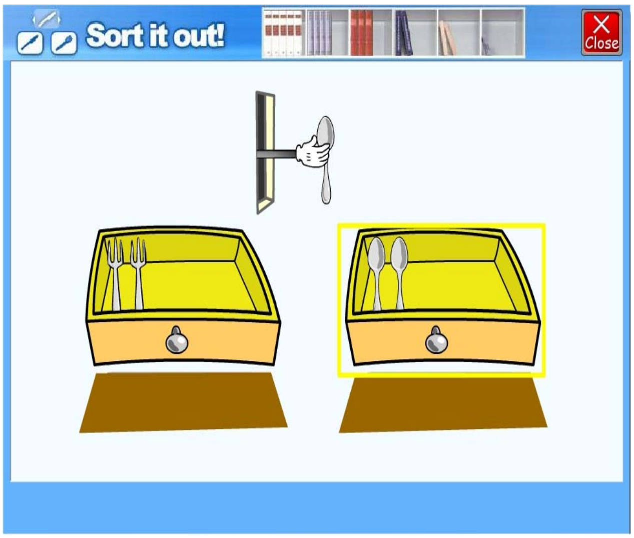

Figure 9. The Sort It Out program.

Spin. This program was based on a slot machine in which the user has to calculate the difference between two times of day randomly displayed on two reels (e.g., 9:00 and 11:00) and to "nudge" the correct time difference into place on the third reel (see Figure 10). Many of the students were familiar with slot machines and enjoyed using the program. The students who were not able to select a correct answer immediately were assisted and shown how to use their fingers to work out the difference. This led to most of the users getting the correct answer, which was a good achievement. Since Spin was designed for Level 3 students, it was found to be rather advanced for Pre-entry level students. It was suggested that a simpler version with fruit symbols or numbers could extend the range of users who could benefit from this program.

Figure 10. The Spin program.

Snap. In this game, two users play each other while sitting at separate PCs. Each had a virtual pack, or deck, of cards and took turns playing a card. When a pair occurred, the first player to click on the two matching cards was awarded a point. Clicking incorrectly lost a point. Entry level students enjoyed the competitive element of this program, playing against a classmate. Sometimes they found it hard to distinguish whose turn it was and the game sometimes allowed both players to either win the same "snap" or to get the wrong answer. This was not necessarily seen as a drawback by the evaluators or the tutors and it seemed to add to the fun for the students.

Life Skills

In the program on personal care, designed for Pre-entry level students, the user was shown a set of images to convey the sequence of actions in daily tasks, such as washing or cooking (see Figure 11). They were then asked simple questions to test their knowledge of the order of the actions. Students identified with the activities, which they found stimulating.

Figure 11. The Personal Care program.

Slideshow Author and Presenter

A program called Slideshow Author (a simple equivalent of Microsoft PowerPoint) was developed for creating and viewing slide presentations as part of a learning activity. This allowed the tutor to set up resources and to create slideshow templates for students to view or add to. These could then be assigned to particular learners through the VLE. The templates could be on topics of particular interest to the students, such as learning activities, home activities, college trips, or holidays. A simpler tool called Slideshow Presenter allowed students to add text, images, video, or background sounds to personalize the slideshow. They could then "play" the result back to themselves or to others. The tutors considered that these tools held a lot of potential since they allow students to be creative and to express themselves by describing their own interests and activities, or to present a story, possibly using their own photo images.

It was expected that Entry level students in particular could create their own plans as a sequence of pictures—such as making beans on toast, going to the shops, or going on holiday—and later see whether this was what happened in reality. The students could then change the sequence to match their experiences. The tools were accessed online so that resources could be shared with other classes and colleges via the VLE. The students liked to see the pictures of themselves on the computer or the work they had done incorporated within slide shows. Figure 12 shows a slideshow being developed in Slideshow Presenter by a learner of a social event, possibly using a template developed in Slideshow Author. Figure 13 shows the slideshow being played. (The actual photographs used in the slideshow have been replaced here by cartoon images.)

Figure 12. A slideshow being created by a learner in Slideshow Presenter.

Figure 13. The slideshow with symbols incorporated being played.

The evaluators made further suggestions to improve this program, reflecting the need to adjust the capabilities for the various learning levels. Some possible additional features suggested were

- messages from tutors to make students aware of new presentations they have to view or complete;
- adding text to images to add context for some users; for example, an image of a cup could be labeled “cup of tea”; and
- an automatic slideshow Play option for students at earlier stages of learning.

The colleges within the partnership started using the tools and building up libraries of pictures (including photos taken by the students in this study and other college students) as resources for inclusion within slideshows. The system was being developed with access levels so that resources could be shared across a class, between classes, and possibly between the different colleges. Speech output for text could also be included so that sentences in a slideshow could be spoken. However this would need to fit with any additional sounds that might be selected to accompany the show. It was thought that the adaptability of the Slideshow Author and Slideshow Presenter programs meant that they could be beneficial for a wide range of students with special needs and also for primary school pupils in general.

VLE Login and Navigation

The VLE login process required the user to select three symbols in sequence from an array of nine. This process taught the students the idea of logging on to a system (see Figure 14) to

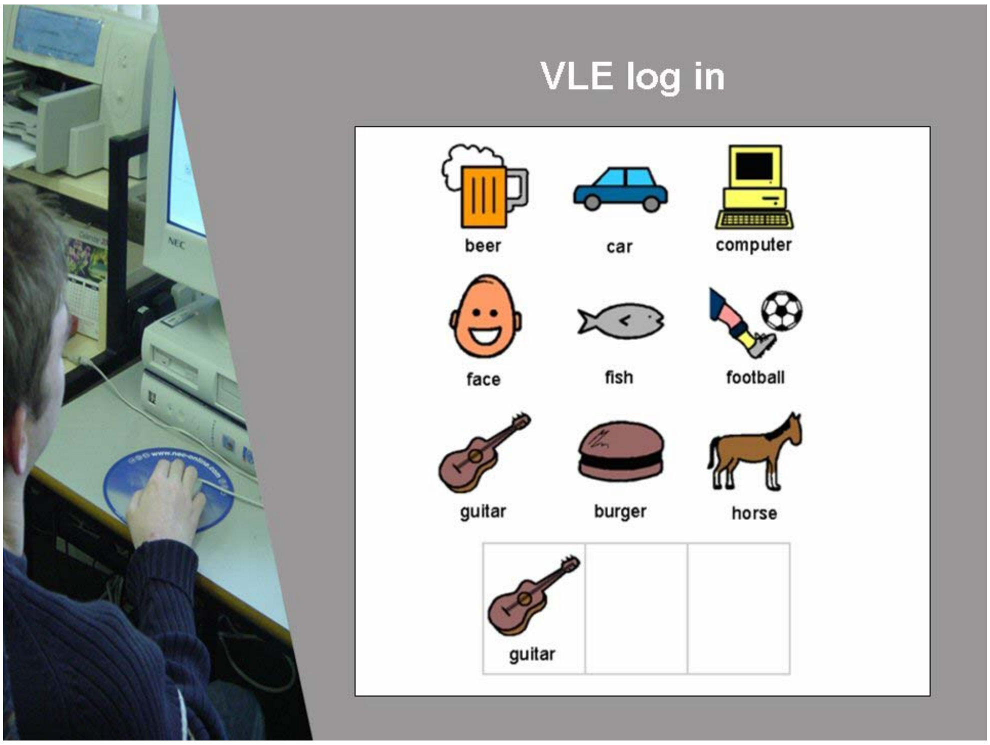

Figure 14. The Portland Partnership VLE login.

give them access to programs relevant to them. Within the VLE, speech output was used to prompt the user about what to do and to reinforce what was presented on the screen. Thus as the switch scanning rectangle passed over each login symbol, its name was read out.

Some of the users became confused when the speech output lost synchrony with the symbols; this problem was addressed in the final version of the VLE. The users had to confirm each selection of a symbol, which helped avoid errors in selecting the symbols but also made logging in a slightly lengthy process. An alternative suggestion was to provide a Delete or "start again" function if an incorrect symbol was selected. However the users were generally happy with the VLE login facility and were able to use it successfully.

After logging in, the student was presented with a main menu of text with symbols providing access to the different facilities. They could choose to open their e-mail, learning programs, or timetable programs (see Figure 15).

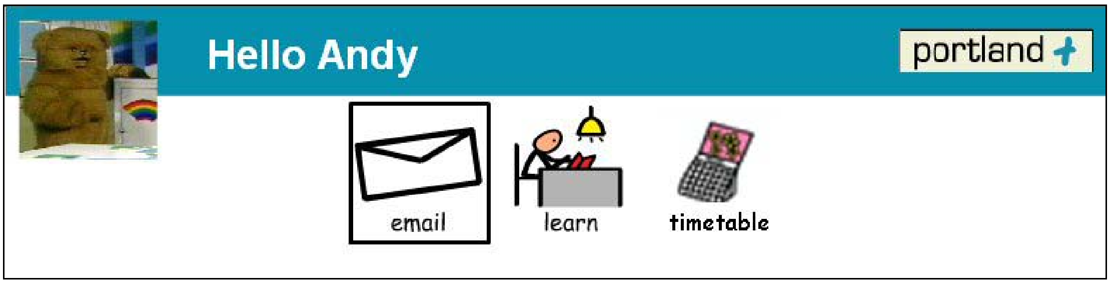

Figure 15. The Portland Partnership VLE main menu.

E-mail

A simple e-mail program was developed within the VLE. The user could choose either to read his/her incoming e-mails or to send an e-mail to his/her tutor or to a classmate. Students could choose the recipient from a list of names accompanied by pictures to help identify the correct one. The e-mail was composed by selecting a topic area (as the subject) and a sentence in text form, supported with symbols and speech, from a predefined list. Although this gave the students only limited options for topics and/or composition, it provided an ideal starting point for students with severe disabilities to experience e-mail communications for the first time. Using the e-mail also gave them a sense of achievement. One Entry level student preferred his e-mail to be presented in words rather than symbols, indicating a need for flexibility of display of e-mail. Some students also wanted to communicate with more flexibility and options than the fixed phrases allowed. The list of phrases could be extended by the class tutor.

Tutor Tools

When the tutor logged into the system, he/she accessed a set of VLE management tools via the main menu options: Home, Administration, Learning Materials, Features, and so on. The VLE was context based so that when a tutor logged on, he/she was given access to just the classes within his/her responsibility. In setting up access for a student, the tutor stepped through a number of stages to guide the process. Part of this was to set up each student's method of input, as shown in Figure 16.

In setting up students within the VLE, the tutor needed to be prepared with suitable pictures and audio files to personalize the students' identities within the VLE. Initial tutor reactions to the tools within the training sessions were positive. A simple user guide was also prepared by the project to support the tutors after the training.

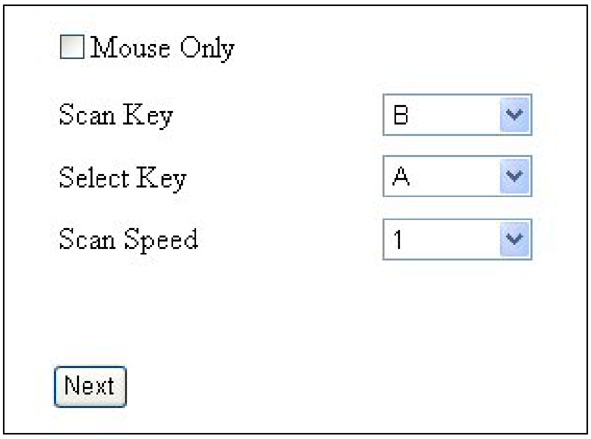

Figure 16. Setting up a student's input device within the Portland Partnership VLE.

Ratings by Students

Each student was asked to give a satisfaction rating for each program using the 5-point smiley scale (1 = *Likes program very much,* 2 = *Likes program moderately,* 3 = *Neither likes nor dislikes program,* 4 = *Dislikes program moderately,* 5 = *Dislikes program very much)* so the lower the value, the better the rating. They were asked to indicate a particular face on the scale (rather than choosing any point, possibly in between the faces). The learners were found to do this naturally. The average rating for the various programs was between 1.0 and 3.0 indicating that the programs were regarded positively by the students. Specifically, the learning programs received average ratings between 1.3 and 2.7, the VLE login process received a 1.7, and the e-mail program was given an average rating of 3.0.

Student Progress Using Learning Materials

By the end of the project, a wide range of learning tools had been produced. Although these had only been evaluated over a relatively short period of a few months, comments from the tutors indicated that students had benefited from them and progressed as a result. Some example tutor comments are presented below.

Pre-entry Level Switch Users

> *This student has become much better at using the computer. She now uses a "Big Mac" (large switch), with a recording of her own voice, as part of a group. This is a huge breakthrough. She does not yet focus on the screen but is using the cause and effect of touch equals sound. The programs have benefited this user very much.* (Student with cerebral palsy and limited verbal communication)

This student is now much more aware of the purpose of a switch and now links it with the sound it produces. We are now working on awareness of the screen. It is great that using the switch helps to involve this user much more in group activities. (Student with cerebral palsy, nonverbal communication, and restricted motor skills)

This user enjoys using all programs and they have really helped his concentration. He now chooses to use the computer—he would not use it last year. These programs will benefit this user very much. (Student with autism and nonverbal communication*)*

This student continues to thoroughly enjoy using the computer and it is proving to really help in developing his communication skills as well as his interactions with others. He is becoming very familiar with the programs and it would be good if he had some at the next level. (Student with communication difficulties and in a wheelchair)

This student enjoys using the computer if he likes the look of what is on the screen. His interest is quick to wander and it would be useful to have activities that continually change so to assess understanding rather than learning the routine. (Student with limited verbal communication and in wheelchair)

Entry Level Mouse Users

This student preferred the programs where he had things to do. He was amused by details and programs showing things going wrong or slightly rude scenes. [In the games programs] he wanted to drag players around [rather than simply click on them]. (Student with hemiplegia, learning difficulties, auditory defensiveness, and modulation)

Enjoyed programs generally. Liked to explore and successfully discovered hot spots. He wanted to see himself on the video. (Student with learning difficulties and Soto's syndrome)

He was generally successful and recognized other students on the video. He was able to click on items in cause and effect scenes and remember which ones he had chosen. He was able to click on the rocket at different stages to see the different colors. [In an early prototype band playing program] he wanted more band members to be animated and play their instruments. [Note: In the final version, all the band members played.] (Student with learning difficulties, spina bifida, and hydrocephaleus)

A more advanced program like the Slideshow Presenter would be useful for this student. (Student with Worster-Drought syndrome and learning difficulties)

RECOMMENDED VLE DESIGN FEATURES FOR USERS

An important aim of the study was to identify features that can improve the effectiveness of learning environments in general for students with special needs (severe cognitive and physical disabilities). The evaluation produced a number of recommendations, as listed in Table 2 and described in the following sections.

Table 2. General Recommendations for VLE Facilities and Learning Programs.

Category	Design recommendations
VLE facilities	Simple method of login tailored to individual students. Clear menu to select and launch programs.
Tutor information and control	Indication of appropriate educational level. Easy set up for individual students.
Learning program content	Student identification with learning materials. Fun elements. Variation to maintain interest. Versions to match different ability levels. Allow students to function on par with mainstream users. Games allowing for interaction or competition with classmates.
Interaction facilities	Speech output support. Exploration of on-screen elements. Design to match the range of student capabilities within the classroom. Clear and consistent switch scanning rectangle. Clear areas to click and consistent navigation.
Feedback to students	Alternatives to words and numbers. Audio/visual indications of success or failure. Certificates of completion or achievement.

VLE Facilities

Simple Method of Login Tailored to Individual Students

Symbols may be used as a means for students to login to a system by, say, selecting three symbols in a certain order from a set of nine symbols. Rather than requiring confirmation of each symbol after entry, it may be preferable to allow further attempts if the user makes a mistake. For students who find selecting three symbols difficult then a simpler login, selecting just one or two symbols should be available. For more advanced learners, login sequences could have a learning aspect to them, for example, it might symbolize what a person needs to remember before leaving the house, such as keys, wallet, and mobile phone. Another solution that could be explored in the future is the use of biometrics, such as fingerprint recognition, allowing students to access the system in a simple way. However the benefit of learning a more standard method of login is that it gives students practice when using computer systems in general.

Clear Menu to Select and Launch Programs

Learning resources within the VLE should be presented in a clear, attractive, and accessible way so that students can decide which program to choose without help from a tutor. A menu of program names simply presented as text will be too complex for many of the students with cognitive disabilities. Instead menu items should appear as bright, simple, and distinct images. The inclusion of the name of the program with the image will assist those students who cannot read or identify words. The use of speech output to read out the names as the user moves the mouse cursor over them or when the switch scan rectangle frames them will also make the menu more accessible.

Tutor Information and Control

Indication of Appropriate Educational Level

Students are assessed as being at a certain level for literacy and numeracy (e.g., Entry level for literacy, Level 1 for numeracy). It is helpful if learning programs are labeled with the appropriate level as a guide for tutors. The VLE could also include a customization feature to present to each student programs appropriate to his/her particular level.

Easy Set Up for Individual Students

If the computer is shared by several learners, the tutor should be able to easily modify the input device settings and user interface to suit different students' needs. The VLE should be able to manage this by changing the settings as each user logs in. In the Portland Partnership project, a new switch was designed to hold the settings for each student (e.g., preferred switch scan rate and symbol set) and to communicate them to the VLE via Bluetooth technology (Brown et al., in press).

Learning Program Content

Student Identification with Learning Materials

In general, students like to see or use content that they can identify with, for example, life skills such as washing, dressing, or making breakfast. Showing mishaps like burning toast can be reassuring for students provided they are advanced enough to see this as representation of an event. However others at an earlier development stage may find such events disconcerting.

Most students enjoy making presentations from pictures or video sequences that include themselves, their tutors, or their fellow students. Many of the Portland Partnership programs were specifically designed to include people in wheelchairs performing actions (dancing at a party, playing in a band, or playing football) to which wheelchair students could relate.

Fun Elements

Programs containing fun elements and details are normally enjoyed by students and encourage them to use the program again. For example, in a program showing a pop band, the name of one of the colleges was printed on the drum. Visual humor in programs such as Party and Cinema also appealed to the students. Another example is the Web site program Singing Horses, produced by Sveriges Television (SVT, 2002), a national publicly-funded television broadcaster in Sweden. Within it, four horses are shown standing by a fence. Clicking on each horse animates it to sing a part in harmony, providing an enjoyable cause and effect activity allowing fairly complex musical sounds to be made with simple inputs.

Variation to Maintain Interest

Students enjoy interactive scene programs, but if the programs follow a set sequence, they can soon become too familiar. Minor levels of variation can create interest for the students, such as in the display of colors in a fireworks program when the user clicks on a moving rocket. In a music program with a pop band, the musicians can play one of several different bursts of music, selected randomly, to add variety.

Versions to Match Different Ability Levels

It may be appropriate to develop different versions of a program to match the various cognitive and physical ability levels of the learners. The Portland Partnership program Pairs had different versions, one using colors and the other using time, to provide different levels of learning targets for students at various stages of learning. This approach also provides a learning path for students to follow.

Allow Students to Function on Par with Mainstream Users

An attraction of e-mail is that it allows students to communicate in the same way as mainstream users. This may be used for students to communicate with the tutor and to receive instructions or help. Sharing images attached to e-mail messages is also an attractive facility for severely disabled students.

Games Allowing Interaction or Competition with Classmates

Students with sufficiently advanced development enjoy games where they can interact or compete with each other. However players will often have very different abilities and reaction times. If the program can detect if one player is always winning and then adapt to make it easier for the other player, then this may be an effective strategy. Tutors also value programs that can be played by two or more students together where they can learn turn-taking skills, such as throwing and catching a ball across a net. A program like Singing Horses, mentioned previously, could also be extended to be a group activity, with each of four students controlling one of the horses.

Interaction Facilities

Speech Output Support

Students with cognitive disabilities can be assisted with speech output of program prompts, selection menus (possibly synchronized with switch scanning), and e-mail messages. Therefore, the inclusion of recorded or synthetic speech output support should be considered where possible. It has been noted that a human voice may be more intelligible and appealing for learners at earlier milestones (Copestake & Flickinger, 1998) although synthetic speech is acceptable if it has a natural sound (Tiresias, 2006). In the Portland Partnership learning programs, the general approach was to read aloud an instruction with a pre-recorded voice to guide the user when the program started. It is important that the speech output always matches the current stage of the learning program or game. Within the classroom, speakers and headphones should be provided to make best use of speech and audio facilities within the programs.

Exploration of On-Screen Elements

Within interactive scene programs, students will expect to be able to interact freely with all the items shown. For example, in a kitchen where they could select the food mixer or kettle, they might also expect to be able to open drawers and cupboards. Providing interaction or animation for as many objects as possible in a scene seems to increase the student's engagement with it.

Design to Match the Range of Student Capabilities Within the Classroom

Within the VLE a range of programs should be developed to match the range of student capabilities within the classroom. In general, though, learning programs should be simple to operate without requiring complex interactions or manipulations. For example, in a game that requires the matching of paired cards, the student may be shown a card and simply have to click another that matches it. There may be a requirement for even simpler programs for certain groups of students, where they simply click their switch to step through a sequence of images that illustrate a story that is read aloud (using recorded or computer-generated speech) or to hear a sequence of interesting sounds. More advanced students may be able to manage and benefit from more challenging interactions, such as dragging objects across the screen or clicking on a moving object. Some programs may be designed to offer different levels of use to match students' abilities, allowing them to do more as they progress.

Clear and Consistent Switch Scanning Rectangle

For switch users, the scan rectangle should stand out clearly from the background. Ideally all programs within a VLE should have the same style of scan rectangle, but allowing the appearance to be customized for individual users. For mouse users it should be possible to turn the scan rectangle off.

Clear Areas to Click and Consistent Navigation

When a student first uses a program, he/she may click on different items to find out how to activate them. For example, in a football game he/she may click on the players, the football, or the goal. Clickable objects should therefore be very intuitive and be made large enough for students with more limited motor abilities. If the user needs to click on a particular point within a program (e.g., the fuse of a firework), this could be indicated with an arrow. The technique of *audio rollovers* may also be used. When the cursor moves over a clickable area, its name or an instruction is spoken, for example, "Kettle" or "Click here to turn on the kettle."

Navigation buttons within the VLE and learning programs should be presented in a consistent style. In addition, they should be placed in consistent locations to help the student learn to operate them more easily.

Feedback to Students

Alternatives to Words and Numbers

Many severely disabled students cannot read text and so instructions or captions (e.g., *the score*) are not always accessible to them. An alternative for some games is for the score to be shown as a number in a large text size or as a line of symbols, such as footballs, to represent the number of goals. In the card game Snap, large ticks and crosses were displayed to indicate a match or no match.

Indication of Success or Failure

Most students need some kind of feedback or reward to motivate them to complete a program and to progress to higher educational levels. A combination of visual and audio feedback (e.g., a smiling clown's face with a fanfare for a correct answer and a frowning clown with a downbeat sound for an incorrect one) is an effective way to provide this. However it should be possible to control the volume of any sounds or to turn them off if they are disturbing others in the classroom.

Certificates of Completion or Achievement

Learning programs can be designed to generate a personal certificate that can be printed to show what the student has achieved. This can boost the confidence of each learner and give him/her an added sense of satisfaction. The VLE itself may be designed to generate the certificates containing the student's name, the program he/she used, the date awarded, and possibly the score attained. The program could also generate a smiley scale for the learner to provide feedback on what the student thought about the activity; such a process was used successfully in the WWAAC project (Nicolle et al., 2004).

CONCLUSIONS

The evaluation has shown that the Portland Partnership software has had a positive impact on learning by students with severe cognitive and physical disabilities. This is supported by the comments from the tutors who experienced positive progress for most of the students involved in the trials. The VLE was tested only to a limited extent, but the feedback from the tutors and students indicated that it is a useful environment for students to access learning programs and for tutors to manage this process. Elements such as the login facility worked well and students particularly enjoyed the idea that they could send messages to others, although in a simpler form than standard e-mail. A timetabling facility also gave students the chance to choose activities for themselves.

The successful development of the learning programs has been based upon successful project collaboration between developers and educationalists, and through a process of iterative design and development that responded to evaluation feedback and tutor comments. To meet the needs of students with less developed capabilities, the Portland Partnership project has started to develop some very simple programs controlled by just a switch to step through a sequence of screens without having to control a mouse or scan rectangle. These include Color Burst, Make a Pizza, and What's Next? (a sequencing program). The further development of such learning programs and VLE facilities should maximize the number of students with severe physical and cognitive impairments who can benefit from them.

ENDNOTE

1. In the UK, Colleges of Further Education (FE) provide courses for students at age 16 and above, from basic skills upwards, particularly work-related training for commerce or industry. These include apprenticeships, National Vocational Qualifications (NVQs), General National Vocational Qualifications (GNVQs), City and Guilds, National Certificates and Diplomas, General Certificates of Secondary Education (GCSE), AS and A Levels. At Colleges of Higher Education (HE) students aged 18 and above study for higher level qualifications including Higher National Certificates (HNC) and Higher National Diplomas (HND), foundation degrees, degrees or postgraduate qualifications.

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APPENDIX

The Elements of the UK Adult Core Curricula Relating to Students.

Level	Curriculum elements
Pre-Entry level Milestones 1 to 3	*LITERACY and NUMERACY* Milestones 1-3 have been subdivided into the curriculum subelements of • Encounter experiences. • Respond with reflex. • Focus attention and give intermittent responses. • Engage with objects and environments. • Show intermittent proactive actions. • Indicate wish to communicate. • Observe results of own actions with interest. • Remember learned responses over longer periods (e.g., for literacy, indicating recognition of a person or object not in his/her daily experience, for numeracy remembering how to activate a switch by pressing a button). • Initiate communication (with gestures, symbols, signs, or words). • Anticipate known events that follow a regular sequence.
Milestones 4	*LITERACY* • Respond appropriately to different requests. • Listen and attend to familiar people. • Understand and respond to a familiar word, sign, or symbol. • Repeat, copy, and imitate up to 10 single words. • Use single words to communicate. • Communicate with a familiar person using single ideas or preferences. *NUMERACY* • Show an interest in counting. • Show an interest in number activities. • Show an awareness of the concept of more.
Milestones 5	*LITERACY* • Respond to simple prompts and questions about events, experiences, or personal details. • Listen and respond to familiar people. • Follow simple requests and instructions comprising two key words. • Make simple requests. • Indicate an object or person • Join in with sayings, rhythms, or music. • Combine two or three words, signs, or symbols to communicate meaning. • Communicate with a person using single concepts, ideas, or preferences. *NUMERACY* • Respond to and join in rote counting to 3. • Indicate awareness, with support, of the numbers 1 and 2. • Indicate awareness of the differences between the quantities of one, two, and many.

Level	Curriculum elements
Milestones 6	*LITERACY* • Listen and respond to familiar people. • Demonstrate that they are paying attention. • Follow requests and instructions, and use phrases containing up to three key words, signs, or symbols. • Use facial expression to enhance meaning. • Ask simple questions to obtain information. • Respond to familiar people in one-on-one discussion. • Take turns. • Cooperate in a group. *NUMERACY* • Join in rote counting to 5. • Understand one-to-one correspondence in a range of contexts. • Count reliably up to three objects, and up to five with inconsistencies. • Recognize the numerals 1, 2, and 3, and with inconsistencies 4 and 5.
Milestones 7	*LITERACY* • Listen and attend to familiar people. • Listen to simple questions on familiar topics and give answers. • Listen to and follow simple instructions and requests of three to five words. • Communicate ideas, choices, and events and make reference to the past, present, future. • Use the conjunctions *and* and *but* to link ideas and add new detail which is beyond that directly prompted or requested. • Make simple requests. • Ask simple questions of others. • Make simple statements about simple and personal matters. • Contribute appropriately to simple oral interactions, including conversations and discussions. *NUMERACY* • Join in rote counting to 10. • Count up to five. • Use the numerals 1 to 5 (e.g., using a large face calculator or keyboard). • Relate numbers to collections of objects reliably to three, and with support to five. • Add and subtract single digit numbers reliably to three and with support to five. • Use the ordinal numbers *first* and *second* (e.g., people in a queue). • Recognize mathematical symbols (=, + . and -) and know how they are applied.

Level	Curriculum elements
Milestones 8	*LITERACY* • Use key words, signs, and symbols in communicating about own experiences and recounting a narrative. • Ask questions using key words, signs, and symbols to obtain information. • Use growing vocabulary to convey meaning beyond words of purely personal experience. • Contribute proactively to simple oral interactions, including conversations and discussions. *NUMERACY* • Join in rote counting to 10. • Continue rote counting upward from a given small number. • Be able to compare two groups of objects with up to five items in each, communicating which is more or less. • Work with the numerals from 0 to 10, know their values, recognize them, use them and (with some inconsistencies) record them. • Relate and add numbers of collections of objects reliably to five, and with support to 10. • Subtract single digit numbers reliably from numbers 0 to 5, and with support from numbers to 10. • Use ordinal numbers *first* to *fifth*. • Recognize mathematical symbols (=, +, and -), such as when working with a calculator to input numerals from 0 to 10.
Entry Level 1 Literacy	*READING COMPREHENSION* • Follow a short narrative on a familiar topic or experience. • Recognize the different purposes of texts at this level. *GRAMMMAR* AND PUNCTUATION • Read and recognize simple sentence structure. *VOCABULARY, WORD RECOGNITION, AND PHONICS* • Possess a limited, meaningful sight vocabulary of words, signs, and symbols. • Decode simple regular words. • Recognize the letters of the alphabet in both upper and lower cases. *WRITING COMPOSITION* • Use written words and phrases to record or present information. *GRAMMAR AND PUNCTUATION* • Construct a simple sentence. • Punctuate a simple sentence with a capital letter and a full stop. • Use a capital letter for personal pronoun "I." *SPELLING AND HANDWRITING* • Spell correctly some personal key words and familiar words. • Write the letters of the alphabet using upper and lower cases. • Use basic sound-symbol association to help spelling, as appropriate for the needs of the learner.

Level	Curriculum elements
Entry Level 1 Numeracy	*WHOLE NUMBER* • Count reliably up to 10 items. Read and write numbers up to 10, including zero. • Order and compare numbers up to 10, including zero. • Add single-digit numbers with totals to 10. • Subtract single-digit numbers from numbers up to 10. Interpret +, -, and = signs in practical situations for solving problems. • Use a calculator to check calculations using whole numbers. *COMMON MEASURES* • Recognize and select coins and paper currency. • Relate familiar events to times of the day, days of the week, and seasons of the year. • Describe size and use direct comparisons for the size of at least two items. • Describe length, width, height, weight, capacity and use direct comparisons for length, width, height, weight and capacity of items. *SHAPE AND SPACE* • Recognize and name common 2-D and 3-D shapes. • Understand everyday positional vocabulary (e.g., between, inside, or near to). *DATA AND STATISTICAL MEASURES* • Extract simple information from lists. Sort and classify objects using a single criterion. • Construct simple representations or diagrams, using knowledge of numbers, measures or shape and space.
Entry Levels 2 & 3	The content of these levels are an extension of the above.

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