section three

Design and development of pervasive healthcare technologies

chapter eight

Human factors and usability of healthcare systems

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8.1 Introduction

Pervasive computing promises to change the way that healthcare is carried out by providing access to patient and medical information "anytime and anywhere." The possibilities for integrating pervasive systems into the daily work practices of healthcare workers depend on the convergence of information technologies into a networked computing environment that is always on and available in unobtrusive ways. However, today's emerging pervasive computing technologies face serious challenges with regard to how such an innovative technology can actually be effectively and efficiently integrated into the day-to-day living and cognitive and physical activities of humans. Thus, we may consider pervasive computing within two dimensions: the technological dimension and the human dimension. Advances in technological aspects of pervasive technologies are moving ahead at a rapid pace including the widespread use of wireless networks, wearable computing, remote monitoring, and surveillance technologies.[1] Despite the incredible potential of this model of computing there are a number of critical barriers and issues related to human–computer interaction that will need to be addressed to achieve its full potential, particularly in complex areas such as healthcare. In this chapter we deal with what we believe to be one of the greatest current challenges to the introduction of pervasive computing in healthcare: the human factor. The technological advances that are occurring in areas such as networking technology, mobile computing, and wearable computing need to be followed more intensively with work in the analysis of human–computer interaction. We will introduce usability engineering approaches to the design, development, and deployment of pervasive computing in healthcare settings. These approaches reflect research that is currently being undertaken in a number of areas including cognitive science, human–computer interaction, and the ethnographic study of workflow. We analyze how we can make new models of computing actually pervade day-to-day work practices in complex healthcare settings. Specifically, we focus on an examination of how pervasive computing can be integrated into healthcare practices in such a way that users can maximize the benefits of new computing capabilities.

Topics discussed in this chapter include requirements for the engineering of new applications and use of scientific methodologies for the study of human factors—"the unique area of engineering that tailors the design of technology to people, rather than expecting people to adapt to technology,"[2] (p. 1). This includes discussion of designing unobtrusive and effective system–user interactions, design and testing of pervasive applications in geriatrics, application of usability engineering methods, and user testing issues. A range of applications where pervasive computing has begun to appear in healthcare will be used to illustrate human-centered methodological approaches to the design and evaluation of pervasive computing. This will include discussion of integration of computerized patient record systems and databases with new pervasive applications; the relation of pervasive computing to telemedicine applications; the need for integrating standards; and usability considerations in the use of mobile devices and Internet-based medical applications. We then discuss the importance of an improved understanding and consideration of human cognition and communication modalities including speech, handwriting, head-mounted displays, and combined approaches. Furthermore, we argue that principled examination of how healthcare workers interact with each other and the world around them is needed for the development of effective and useful pervasive computing applications. The chapter ends with a brief description of a human factors laboratory in development to examine the intersection between human–computer interaction and pervasive computing in healthcare.

8.2 Background: Human–computer interaction (HCI) in healthcare and pervasive computing

In the emerging field of health informatics, a wide range of innovations has appeared, ranging from advances in patient monitoring to the computerized patient record (CPR) system—an electronic repository that allows healthcare workers to enter patient information into a database electronically and retrieve needed patient data and relevant medical information about patients at point of care. These types of systems promise to revolutionize healthcare and form the basis for further advances in healthcare information processing and care, including automated alerts and reminders to physicians and automated invocation of rules and guidelines that interact with patient data to provide advice to healthcare workers. However, perhaps in no other field of research have issues related to human–computer interaction come more to the fore when attempting to disseminate such innovative information technologies. Despite repeated efforts at multiple levels, the widespread use of integrated healthcare information systems, including the CPR, has remained elusive.[3] Deployment of such systems has faced a variety of problems including delayed implementation times, difficulty in integrating new systems with existing systems, and even the difficulty of new information technologies that introduce error into the healthcare system if not designed and deployed carefully.[4]

It has been argued that issues of HCI (i.e., issues involving the study of the design, implementation, and evaluation of computers for human use) may be the most serious barrier to successful implementation of innovative healthcare information technologies in general.[5] In this chapter we take a broad perspective on HCI that encompasses three levels: level 1—the level of the individual user interacting with a system; level 2—the level of the user interacting with an information system in order to carry out real work tasks; and finally level 3—the organizational level where the interaction with an information system is considered in the context of its impact and effect on the organization as a whole. This characterization of the use of new information technologies in healthcare builds on a three-level model of HCI,[6] which provides a useful framework for considering the complex problem of understanding how to best design, test, and deploy innovative healthcare information technologies such as pervasive computing (see Figure 8.1).

Using this model we can consider problems in the acceptance of new technology at each of the three levels. For example, the goal of successful adoption of a CPR system may fail at level 1 if the design of the computer screens and instructions are such that users cannot easily learn how to use the system to enter patient data. Even if a system is designed to work well at level 1, problems may occur once the system is inserted into the complex day-to-day activities and workflow of healthcare work practices, which may involve a variety of team members, contexts, environments, levels of urgency, and complexity of tasks. However, careful analysis and adjustments made to provide effective systems at level 2 do not guarantee uptake and acceptance of a new healthcare information technology, because the effect and impact of deploying such a technology at the organizational level (i.e., level 3) may be an issue. For example, in the context of the CPR, privacy and confidentiality issues at an organizational or political level may restrict the deployment of this technology within an organization such as a hospital. Nowhere in healthcare may careful consideration of each of these three levels of HCI be more germane than in consideration of pervasive computing, as pervasive computing spans all the levels of individual users of systems. Through the application of this new technology in complex work roles and activities, issues may emerge with the increased possibilities for widespread access and dissemination of patient information, along with organizational concerns regarding privacy and confidentiality.

Another perspective when considering pervasive computing in healthcare relates to the extent of human interaction with the system. We can consider

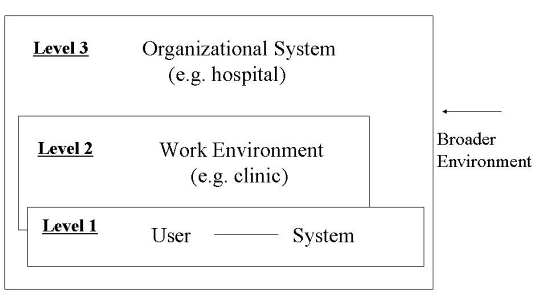

Figure 8.1 A three-level model of HCI in healthcare.

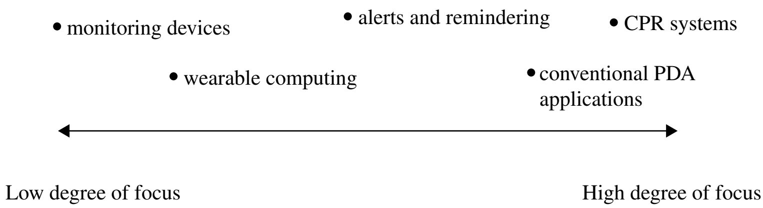

Figure 8.2 Degree of user focus/awareness of system in user interactions in healthcare.

user interaction with pervasive information technologies in healthcare along a continuum, from applications that require continual attention from the user to applications where the technology is "invisible" or interacts to a very limited extent with the user. For example, the user interfaces of many handheld applications (see the right side of the continuum in Figure 8.2) typically represent an extension of conventional desktop user interfaces to mobile applications. With these types of applications, users must focus their attention on the user interface (e.g., to enter medical values into a personal digital assistant [PDA]) when the device is in use and must explicitly insert its use into their work activities. The introduction of a new technology must be understood in terms of how it changes the work activity of the user. To this end, many aspects of human factors from the study of conventional user interfaces are applicable. However, many applications of pervasive computing, including remote monitoring devices and wearable computing, are designed to be used ubiquitously *while* the user carries on work activities (i.e., without switching the focus of attention to interacting with the technology). This is presented in the left-hand side of the continuum shown in Figure 8.2. The implications of this new type of user-system interaction include the following: (1) interaction of the system with the environment is through a variety of modes and involves context awareness by the system; (2) the system may need to be operated with minimal cognitive awareness and effort on the part of the user, which is achieved through the system's context awareness and ability to automatically adapt to new user situations; and (3) a wide range of tasks may be performed by the system without human–system interaction.[7] The implications of these key aspects of many types of pervasive applications will be discussed throughout this chapter.

8.3 HCI and the system development life cycle

In addition to considering the HCI issues described above, to practically design and successfully deploy complex healthcare innovations such as pervasive computing, we must consider the development of the technology along a continuum from initial project planning through analysis and design to eventual system deployment. A useful framework for considering the various methods for improving HCI in pervasive systems (described later in this chapter) is the system development life cycle (SDLC). The SDLC defines a set of stages for system development. The traditional SDLC is characterized by the following phases: (1) planning, (2) analysis, (3) design, (4) implementation, and (5) maintenance and support. Although the exact nature of the SDLC employed in developing an information system may vary in terms of the relationship between these phases and their scheduling, these phases represent activities that are important for developing information systems. One implication of considering HCI aspects of pervasive computing along the SDLC is that the analysis approach taken will depend on where in the life cycle the project is at, as illustrated in Figure 8.3. For example, during the initial phases of development of pervasive applications, a variety of methods may be employed for prototyping different user interface designs by having users respond to and comment on mock-ups of display screens (e.g., for mobile applications) and applying methods of usability testing, as described in the next section. Later in the development cycle, usability testing may involve an analysis of representative users interacting with a system in artificial or realistic scenarios (also described in the next section). Summative evaluations, where nearly completed software products are beta tested, occur late in the SDLC. In health informatics this type of testing of systems has typically involved clinical controlled trials, where one group of subjects (e.g., physicians) receive a new information technology, such as a new handheld application, and another group serves as a control group (i.e., continues to use whichever method they were using before). Such studies attempt to isolate the effect of a system on healthcare practice, but they have been criticized for their inability to provide designers of complex healthcare systems with concrete and detailed information related to HCI, which might lead to dramatic improvements in their design.[8] The remainder of this chapter discusses methods for analyzing HCI that can be employed during the formative evaluation of systems in order to provide iterative input into device and system design and refinement throughout the SDLC.

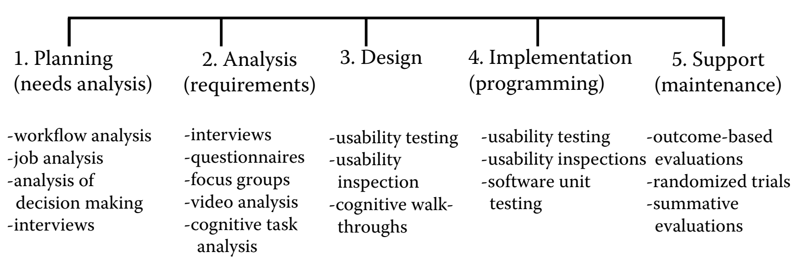

Figure 8.3 HCI approaches to system evaluation throughout the system's development life cycle (SDLC).

8.4 *Usability engineering methods for the analysis and improvement of pervasive computing applications in healthcare*

Usability engineering is a rapidly emerging area in the field of HCI and has provided a set of methodologies for the analysis of complex human interactions with computer-based systems. In this section we describe some of the main methods that are employed for gaining insight into many detailed aspects of HCI in the study of pervasive computing applications. These approaches can be considered along a continuum from experimental laboratory-based studies (presented as the left side of Figure 8.4) to the study of use of devices in naturalistic real-world settings (the right side of Figure 8.4). There is a category of study of HCI that falls between the two categories and involves the use of realistic simulations of real settings and contexts, which mimic those a user would expect to encounter. For example, a laboratory study of a handheld application for entering medical prescriptions might involve subjects coming to a usability laboratory and having their interactions with the application recorded as they respond to artificial medical cases. They might also be asked to verbalize their thoughts as they complete their tasks. A simulation-based study of the same application might involve subjects interacting with a "simulated patient" (i.e., a trained research collaborator playing the role of a patient), while the subject uses the application. A naturalistic study of the same application might involve remote logging and tracking of user interactions with a device as the subjects carry out actual day-to-day activities in a medical clinic. It should be noted that an in-depth analysis of HCI in healthcare may involve a laboratory study of user interaction with a device or application, which leads to testing under simulated conditions and then, finally, to testing in naturalistic settings. To analyze HCI effectively, all aspects of user interaction with the application or device are recorded so that they can be interpreted. This is often done by several methods including videotaping, recording interactions at the device level, and user feedback during each stage of trials. This information is critical for conducting usability tests.

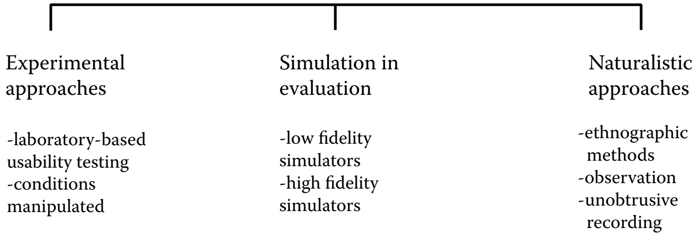

Figure 8.4 A continuum of approaches to evaluating healthcare information systems.

8.4.1 Usability testing

Usability of systems refers to the degree to which they are useful, effective, efficient, and enjoyable.[9] One of the most powerful methods for understanding and analyzing the usability of pervasive technologies is through usability testing.[10] Usability testing refers to the evaluation of information systems by conducting an in-depth analysis of user interactions with the system as users carry out tasks the system or device was designed to support, under either artificial or realistic conditions. Typically this involves video recording the interactions of users with the pervasive device, especially when the testing occurs in a simulated environment. Elements that may be captured are screens of a computer application, logs of the system's behavior, and the physical and verbal behavior of subjects as they interact with the new device and others in their work environment. Under artificial conditions, subjects may be asked to "think aloud" while interacting with a device or carrying out a task that involves the use of pervasive technology. The amount and type of data captured is highly dependent on the type of trial (i.e., it is generally easier to capture more data in a simulated environment versus a real one). Any resulting audio and video recordings of the interaction can then be analyzed posttrial using methods involving the coding and classification of user problems.

Usability testing is based on cognitive task analysis. Cognitive task analysis emerged from the fields of cognitive science and psychology and involves a detailed analysis of humans as they carry out complex reasoning and decision-making tasks.[11] Usability testing typically includes the following stages:[12]

Stage 1—Identification of evaluation objectives. The objectives at this stage may range from testing a prototype design with potential users to obtain feedback on preliminary design issues to testing of near-completed applications to assess reliability and safety.

Stage 2—Selection of test subjects and computer applications. Subjects selected for study should represent the intended end users of the pervasive application. For example, subjects with a particular cognitive deficit should be recruited for studying a system designed to provide support to such populations.

Stage 3—Selection of representative experimental tasks. The selection of appropriate and realistic tasks for subjects to carry out is essential to ensure the validity of human-factors testing. An example would be the selection of realistic clinical tasks to study physicians' use of a PDA application in an emergency ward.

Stage 4—Selection of an evaluation environment. The evaluation environment may range from a laboratory setting (e.g., a usability test site with built-in monitoring equipment, one-way mirrors, etc.) to real conditions (e.g., monitoring use of pervasive technologies within an operating room).

Stage 5—Data collection of user (i.e., subject) interactions with the pervasive technology while carrying out representative tasks. This is the stage where subjects carry out tasks using the technology under study. Data collection can include video recording overt, physical user actions; audio recording verbalizations of subjects; screen recording of computer-based devices; and logging or tracking of system responses and processing.

Stage 6—Analysis of the process data. The data collected in stage 5 are analyzed using a range of methods. This includes coding of transcripts of video and audio interactions to identify issues in the user interaction, problems with human–computer interaction (e.g., problems locating information, navigating through information resources, etc.), and problems with system-sourced activities (e.g., inappropriate context switching by a pervasive application).

Stage 7—Interpretation of findings for system redesign and refinement. The ultimate purpose is to provide feedback to the designers of new technologies about how to improve the design. The cycle of prototype testing, feedback, and redesign may occur several times before the designers and potential users are satisfied with the performance of the device.

The following example illustrates the usability testing stages outlined above. For example, in a study with the objective of assessing the utility and usability of a mobile application for alerting physicians about patient emergencies through a PDA device (stage 1), physicians might be asked to carry out routine daily activities while the experimenters observe (and video record) the physicians before, during, and after simulating an emergency patient alarm using the PDA (i.e., representative subjects carrying out representative tasks using a representative device; stages 2 and 3). The video recordings of user interactions can then be analyzed to assess the efficacy and usability of the device in realistic situations in a laboratory environment (stage 4). Subjects can also be asked about their experience with the system immediately after interaction with the device has taken place, using a method called cued recall. In cued recall, subjects are asked to recount their thoughts about the device while they are shown video recordings of their interactions. The investigators may have specific queries for the subjects as to their thoughts and actions at key points in their interactions with the system or device under study (stage 5). Subsequent to this, researchers can analyze video and audio recordings (stage 6) and incorporate their findings into the iterative design of the system (stage 7).

Usability testing can be easily adapted to analyze pervasive healthcare information technologies and systems. For example, this could range from usability testing involving video recording physicians or nurses carrying out tasks while using a PDA to simulations involving elderly subjects undertaking daily activities while wearing portable monitoring devices. This approach has been employed in the study of devices ranging from mobile handheld applications to analysis of the usability and usefulness of automated alerts and reminders for physicians in simulated emergency situations.[4,13]

8.4.2 Usability inspection

A second methodology adapted from HCI in healthcare that has emerged from a cognitive task analysis approach is known as usability inspection.[14] Usability inspection involves a usability analyst or inspector stepping through or "walking through" use of an interface or system in the context of some real task or activity. For example, an approach known as the cognitive walkthrough involves the analyst (or a team of analysts) stepping through the activities that use a new, and possibly pervasive, technology while recording goals, actions, system responses, and potential problems. Another example is a methodology known as heuristic evaluation. This methodology focuses on identifying violations of principles of human-factors design when a system is used to carry out a task.

Jacob Nielsen[10] has outlined a set of principles or rules to consider when conducting such analysis, including the following:

1. Visibility of system status—The state of the system's processing should be visible to users of a system when they so desire that information.
2. Matching the system to the real world—Real-world language and conventions should be used in user interfaces.
3. User control and freedom—Users should feel like they are in control.
4. Consistency and standards—The user interface and system operations should be consistent.
5. Error prevention—Designers should design interfaces to prevent errors.
6. Minimize memory load—Systems should support recognition (e.g., using menus) rather than recall.
7. Flexibility and efficiency of use—Systems should allow for customization and adaptability.
8. Aesthetic and minimalist design—Often the simplest and most minimal designs are the best.
9. Appropriate error handling—Help users recognize, diagnose, and recover from errors.
10. Help and documentation—Help should be available to users when needed.

These principles can be extended when considering pervasive computing in healthcare. Based on our current work with pervasive devices, we propose the following heuristics or guidelines for the evaluation of pervasive applications:

1. Unobtrusiveness—Direct interaction of a user with a pervasive system should be limited to only the parts of the task where such interaction is necessary (i.e., allowance for visibility when required).
2. Privacy and security—Use of a pervasive device must not violate privacy and security restrictions under normal conditions of use.

3. Emergency override capability—Under exceptional conditions, security and access restrictions may need to be overridden. Such exceptional cases need to be identified and logged for subsequent audit.
4. Appropriate context awareness—Pervasive systems must be able to track the context of use and respond to differing contexts in an appropriate manner.
5. Failure backup—Failure of a pervasive device or its supporting network should be made apparent to the user through some form of notification.
6. Alternative modes—Allowances should be made so that alternative modes of user interaction are available during system failure and recovery periods.
7. Information and alerts prioritization—The system should appropriately prioritize and display alerting or reminder information. This information should be displayed only at essential points in user workflow to avoid cognitive overload.
8. User controllability—The user should assume manual control of the system when needed in the absence of traditional interface cues (e.g., a physician can shut off decision support functionality in situations where he does not feel it is appropriate).
9. Appropriate modality for interactions—The type of system–user interface should be fitted to the task and user's needs.
10. Consistency across modalities—The user should be able to switch methods of interaction and easily recognize where common information is located.
11. Seamless modal switching—The user should be able to switch devices without having to re-input any information.

Applying appropriate design principles and guidelines in the development of effective pervasive applications is difficult, as such applications may often demand seemingly conflicting requirements (e.g., the transparency of operation for ubiquitous applications under normal operating conditions, while providing visibility of operation under failure or certain emergency contexts). The ability to disengage from an interaction with a pervasive system or application may be important at times. This would require users to know where they were in an interaction with the system, which may be difficult if the system is designed to be highly unobtrusive with limited explicit and visible interaction with users. Furthermore, the varied contexts of use of systems in healthcare (e.g., differing situations of task complexity, urgency of medical situations, and differing clinical environments) may make it extremely difficult to develop systems that can appropriately adapt to differing conditions of use. Guidelines such as those presented above can be applied in a principled manner by using a cognitive task analysis approach. For example, analysts may step through the use of a pervasive device, recording violations of any of the above guidelines during testing. In addition, the same guidelines can be used to analyze data collected from the study of subjects interacting with pervasive systems under artificial conditions, simulations, or naturalistic settings. These types of techniques essentially form a category basis for coding and quantifying problems observed by analysts and investigators when reviewing video data of user interactions.

8.4.3 Modeling of workflow

As discussed so far in this chapter, for pervasive applications to be effective they must embody context sensitivity that allows for the system to adapt automatically to changing contexts and situations. The effectiveness of this is directly related to how well the system is integrated with and operates within an appropriate workflow (i.e., the steps in a process from its start to its end) from the perspective of the users.[15] A variety of new methods have appeared for analyzing workflow and the effects of systems on user interactions and task goals. For example, Cysneiros and Kushniruk[16] describe the application of an ontology of nonfunctional software requirements that can be used to help analysts and decision makers reason about issues such as the effects of introducing pervasive devices (e.g., wireless handheld devices) on nonfunctional requirements such as privacy and usability. Furthermore, application of techniques from the area of workflow modeling can more accurately characterize and describe changes in workflow before and after the introduction of devices and healthcare applications (e.g., wireless access to patient records). Along these lines, accurate analysis of the contexts where the pervasive system will be used is essential to develop mechanisms for appropriate automatic switching of contexts that are supported by a system. Recent advances in workflow modeling and requirements gathering using nonstandard approaches offer hope in improving this critical aspect of pervasive systems, particularly through the appropriate mapping of system responses to situational contexts in the healthcare domain. For example, Jorgensen and Bossen[17] describe the application of extended unified modeling language (UML) through case modeling to obtain requirements and refine the design of a pervasive patient record system. Using their approach, three levels of analysis are suggested, beginning with prose descriptions of work processes and proposed computer support, followed by development of formal executable models of the work processes, and completed with the development of testable animations that represent the proposed solutions. Using such an approach, system requirements can be interactively examined by stakeholders (e.g., designers and end users) in the context of potential work processes. Such analysis may be essential for development of pervasive applications as they are often intended to be tightly integrated into complex work activities.

8.5 Examples of HCI approaches to analyzing pervasive applications in healthcare

This section presents a number of projects that examine human–computer aspects of pervasive healthcare systems, with a focus on how the principles and methods described in the previous sections can be practically applied in design and deployment of pervasive systems.

8.5.1 Use of PDAs by physicians

A recent research study examined the relationship between usability problems and prescription errors when physicians used a mobile PDA-based application to write prescriptions and interact with a remote CPR system.[4] A simulation approach was chosen for studying interactions of physicians with the PDA device when carrying out a set of realistic tasks (e.g., interviewing patients and ordering medications). The study design involved full video and audio recording of the screens of the PDA and of the subject's interaction with both the device and with a simulated patient, while the subject carried out tasks that the device was designed to support. To analyze the resulting data, transcribed audiotapes of the physician subjects' verbalizations were linked to the corresponding video sequences of their interactions with the handheld device. Results indicate that specific categories of usability problems can be identified with considerable accuracy early in the design of a device. Examples of these include problems due to limited screen size and lack of display capability in order for users to have the opportunity to view a summary of medications entered prior to submitting a medication request. The occurrence of usability problems in user interactions with the device was noted under one of the following categories: display visibility problems, navigational problems, input problems, printing problems, and speed problems. By coding the data in this manner, as well as by coding actual medication errors during the simulation sessions, it was possible to estimate the extent and probability of an identified usability problem predicting an actual medication error *prior* to finalizing the design of the application.[4,13] Work such as this promises to ensure that pervasive applications actually improve healthcare efficiency and safety, rather than inadvertently increasing error, as has been shown in recent studies of use of automated medication entry applications.[18]

8.5.2 Use of Web-based applications by chronically ill healthcare consumers

Pervasive applications in healthcare using application platforms such as the Internet and innovative devices such as smartcards (described in Section 8.5.3) will likely make patient data accessible not only to healthcare professionals at various and mobile locations but also to a wide range of stakeholders including patients themselves. As described earlier, CPR systems constitute large repositories of patient information (e.g., vital signs, medical images, and patient demographics). In a related line of research, we studied the extension of a Web-based CPR system, which allowed thousands of physicians at Columbia Presbyterian Hospital in New York to access the records of their patients from various locations via the Internet.[19] The project aimed to extend access of the records not only to physicians but also to patients.[20] Security issues were paramount in designing an application that would allow for an architecture that is open enough to keep the system versatile, while limiting access to appropriate users in appropriate contexts. Use of the resultant system was evaluated over a thirty-six-month period and involved thirteen subjects in a process of iterative development and refinement; the study provided details about patient and physician system access such as review of patient data, access to educational resources, and decision support—all activities were automatically recorded into a log file. The results of the study indicated that allowing such access could have a positive impact on face-to-face doctor–patient encounters while keeping security risks at a minimum. The technique to remotely analyze such applications resulted in the design of an application known as the Virtual Usability Laboratory (VUL).[21] The VUL is designed to unobtrusively monitor users of Web-based applications remotely while also providing the ability to automatically query users after they interact with the application being studied (e.g., querying users after they interact with a remote CPR system). Data from remotely monitoring a large number of users can then be integrated within a centralized database connecting usability data, such as browsing patterns, system invocations, and user interactions, with medical and demographic data related to those users. Successful and widespread use of pervasive technologies within healthcare will require close integration with the growing number of CPR systems being installed at various institutions. Additionally, monitoring and tracking users will be needed to assess how to design and refine usable and useful applications. Effective pervasive applications in healthcare need to interface seamlessly with interoperable databases and CPR applications. This goal is still somewhat elusive because there is now a plethora of different CPR systems in use in healthcare, with individual hospitals often having a number of different CPR systems. However, the movement toward adopting messaging and medical vocabulary standards (e.g., using HL-7 standards for the exchange and integration of electronic information) will allow for increased integration of hospitalwide applications and clinical information systems with innovative mobile-based applications.

8.5.3 Use and usability of smartcard technology

Another exciting example of a pervasive application in healthcare is the integration of smart data and smartcard technologies with CPR systems. The use of smartcards (card-sized devices with a microprocessor that contain patient-specific information and that can be carried around by patients) has been adopted in a number of countries.[22] To date, such applications have been limited to storage of a relatively small amount of basic demographic and medical data about patients. Data on these mobile devices can be integrated with applications running clinical guidelines and rules, resulting in alerts or reminders to users (e.g., physicians or patients) via a remote device. Wearable electronic bracelets and radio frequency identification devices (RFIDs) can be used for patient identification and can contain patient-specific information about drug allergies, ensuring that appropriate medications are given to patients.

The usability of such devices in real hospital settings has been problematic for a number of reasons. In particular, issues in appropriately updating the remote source of patient data as well as security issues, such as privacy and the need to detect unauthorized access to such patient-specific information, remain problematic. In general, developing interfaces with pervasive devices allows for unfettered access by authorized users while preventing unauthorized access has remained one of the more problematic issues to be resolved before such devices become common. In a recent article, Coiera and Clarke[23] argue for the development of a framework for considering "e-consent" to guide access to electronic health information. Their model distinguishes between a general consent model (where blanket consent is given to healthcare organizations to access the patient's data, and exceptions to general access are specified) and a general denial model at the other extreme (where access is denied by default, unless specified otherwise). Application of usability engineering approaches, such as simulation techniques described above to test such devices in a range of realistic situations and scenarios, will be necessary to ensure that such systems actually support workflow and security concerns and do not hinder patient care in real hospital settings.

Thus, although potential integration and remote access to institutional CPR systems are goals of a number of research projects, they need to await advances in both wireless networking and the resolution of privacy and confidentiality issues. In one recent study conducted in Canada, the factors influencing the adoption of smartcards were investigated after tracking use of the cards by 299 professionals and 7,248 patients, who used smartcards for a year.[24] From interviews with both patients and physicians, results strongly suggested that users were very sensitive to the need for clear benefits of use of the technology in order to adopt it widely. From the physicians' perspective the relative advantage of the system was linked directly to how complete the recorded information is, while the factor most likely to influence adoption of the system by patients was how much ownership the patients felt they had over their own health data.

8.5.4 Pervasive computing and the elderly—toward a framework for analysis of pervasive applications in healthcare

Another area in healthcare where pervasive applications currently holds considerable promise is in the support of care for the elderly and impaired populations. In recent years there has been a shift in the provision of patient care. Improvements in the quality of healthcare information and communication technologies (ICTs), medical care, treatments, and the rise of consumerism have reduced the need for hospitalization, shifting the burden of care from the hospital to the community and from the health professional to the individual healthcare consumer. Such advances in the provision of care have led to improvements in patient quality of life, increased cognitive and functional independence, better patient monitoring, self-management of and control over disease, and reduced health service utilization (i.e., the number of hospital, physician, and home care visits and hospital length of stay).[25] Nowhere has this trend been more evident than among the elderly (i.e., those over sixty-five). Increasingly, elderly healthcare consumers are living better, more independently, and staying at home longer (without the need for institutionalization). In addition to these trends, elderly persons have become the most significant and growing group of computer users, using new technologies to learn about, monitor, and manage their health. It is this interest in the potential assistive nature of new technologies among elderly consumers that has led to the growth, development, design, and evaluation of a wide range of pervasive computing technologies for the elderly. In recent years, significant interest has emerged among software and hardware developers and elderly consumers about the potential health and independence benefits associated with the use of pervasive computing technologies in the home by an older adult.

As we age we experience significant physiologic changes. Systems within the body do not function as well as they had when we were young. Furthermore, as we age, a combination of genetic and lifestyle factors causes us to be more prone to developing acute and chronic conditions that affect our cognitive and physical functioning, therefore impeding our ability to live independently or with our families at home. For example, the ability to perform activities of daily living (ADLs) (e.g., bathing oneself) and instrumental activities of daily living (IADLs) (e.g., grocery shopping) will often determine if an older adult is able to manage at home or requires some form of assisted living or institutionalized living arrangement. Software and hardware designers and developers are exploring the value of pervasive computing technologies in supporting older adults' changes in cognition and function. More specifically, four key areas of research have emerged: (1) promoting safety, (2) aiding cognition, (3) improving social interaction, and (4) promoting functional independence. These areas of research overlap in the domains of aging and pervasive computing technologies including the remote monitoring of health status. The evaluation of HCI aspects of such systems can be understood in terms of several critical aspects. Figure 8.5 illustrates a framework reflecting the critical aspects that need to be considered when analyzing the impact of pervasive technologies designed to support the elderly and impaired.

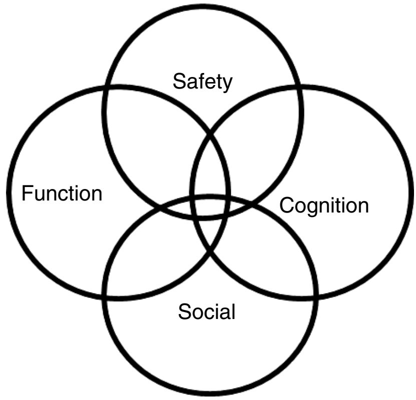

Figure 8.5 A framework for considering HCI aspects of pervasive systems for the elderly and impaired.

8.5.5 Monitoring health status

A wide range of research projects is currently underway to explore the value of using pervasive computing technologies to monitor patient vital signs (i.e., heartbeat, respiration, blood pressure, and temperature). In recent work, pervasive computing technologies are being used in a nursing home to monitor residents' vital signs.[26] It is believed that the ongoing monitoring of vital signs will help healthcare professionals to identify healthcare crises before they occur. In this case, the technology would help the health professional observe trends in bodily functioning over the course of a month, week, day, or minute by minute. If changes in bodily function can be identified by changes in monitored vital signs, it is possible that early medical attention could be sought before a critical event, such as a stroke or heart attack, occurred. Another benefit of using such devices is a potential increase in the efficiency and effectiveness of health professionals. Automating the collection and recording of vital signs would mean that health professionals such as nurses would need to spend less time manually collecting and documenting information, an activity that has been found to take up a significant amount of time. This would allow health professionals to spend more time reviewing and evaluating patient health data and conducting other forms of assessment, resulting in better patient care. The benefits of using such technologies in the clinical setting are significant, but the implementation of such technology highlights the importance of usability for both health professionals and patients. From a patient perspective, pervasive technologies that transmit information about a patient's health status need to be lightweight, easy to wear, and of a sufficiently small size that they do not impair mobility or independence.[7] For health professionals, new knowledge and skills need to be developed to help them relate information about physiologic function to critical health events to patients—an area of research that is being studied increasingly. Decision-support systems that help health professionals to review and understand data will be critical, as such sheer volumes of data that could be logged automatically could lead to cognitive overload and subsequently to increased, rather than decreased, work for the health professional. Pervasive computing technologies could help health professionals spend less time on administrative activities and more time assessing and managing the care and treatment of patients. However, care must be taken in technology design to ensure that users are not overwhelmed with information.

8.5.6 Promoting safety

Pervasive computing applications have been cited to improve patient safety. The aim of many of these applications is to prevent injury arising from physical or cognitive deficits while promoting independence. For example, pervasive computing technologies (e.g., tracking systems) are being used in acute and long-term care settings to prevent cognitively impaired patients from wandering away.[27] These technologies can be broken down into those that are used for the purposes of tracking patients and those that monitor patient movements and, based on these movements or identified behaviors, signal health professionals that the patient may have or has already injured themselves. These technologies are a significant advance over traditional methods of caring for patients. For example, current systems used to care for cognitively impaired patients who wander limit patient independence, restricting the patients' movements (such as the use of locked units), or use alarms that can unintentionally startle or frighten patients. New tracking systems allow patients to wear bracelets or badges that provide information to a central monitoring system about where they are located in a facility at any point in time. Although still in development, another pervasive computing technology that holds great promise toward increasing patient safety is the falls monitor.[28] Currently, clinicians are limited in their ability to prevent a fall or help a person who has just fallen. Clinical attempts to prevent falls have resulted in the development of pen-and-paper scales that measure an individual's level of risk and the implementation of strategies that can be used to reduce the likelihood of a severe fall. These include injury-proofing the home (e.g., removing mats) and developing clothing (e.g., hip pads) that cushions individuals when they do fall to hopefully prevent fractures. Pervasive computing technology could move us beyond these limited approaches to try and avoid falls, providing us with information about the types of activities and movements that lead to falls. In addition to this, current systems have successfully warned health professionals or patients of the potential for experiencing a fall, encouraging individuals to change their behavior to reduce the risk. Pervasive computing technologies have also been used to successfully identify the movements of an individual who has fallen.[28] Deploying such technology in the home could help an older adult make decisions about the types of behaviors he or she undertakes that may place him or her at risk for falling. Additionally, an automatic fall detection system could get immediate assistance by notifying caregivers or health professionals if the individual did experience a fall. This would effectively reduce complications caused by the "long lie" experienced by people if they are severely injured by a fall and have to wait for someone to find them. These systems are currently in development and their use will depend on the ability of the system to recognize impending or actual falls accurately, without generating an unacceptable level of false positives (i.e., false alarms).[29] Presently, such systems have some ability to detect some types of falls and not others. More research is needed to develop a comprehensive set of fall-related behaviors and then construct a system that is effective in detecting the potential for a fall as well as a fall itself. Implementation of this type of pervasive technology may be difficult as results from a focus group suggest that potential users perceive these types of systems as infringing on their privacy.[28] Furthermore, there are concerns about who would have access to the monitoring data. Finally, there is a need to create usable interfaces that allow an older adult who has sensory-motor, cognitive, and functional impairments to interact with these systems.

8.5.7 Aiding cognition

More recently, pervasive computing technology advances have been created to act as assistive devices and help the cognitively impaired. A large focus in this area is the development of reminder systems. Reminder systems have taken various forms: from systems that are used by those individuals who have mild impairments (e.g., medication reminder systems for people who forget to take their medication) to those used by people with significant impairments (e.g., a cueing device to help someone remember the steps involved in washing, cooking, or dressing). One such system provides the individual with a visual reminder of the last task completed.[30] For example, if the individual had just finished brushing her teeth, a picture would appear providing her with a reminder that she had brushed her teeth and another picture would be provided cuing her to wash her face. Although this is an interesting approach toward helping older adults with cognitive problems, it remains unclear if such systems could be successfully employed by the cognitively impaired adult as a form of cueing or as a reminder. For example, could a cognitively impaired individual learn to use such a system or would it go ignored or unused because the system was too difficult to learn or perceived as a form of cognitive overload? Also, would such a device lead to cognitive overload during the actual task? Many questions remain unanswered and need to be addressed. The application of usability approaches to these problems may go a long way to shedding light on such issues. As this is a particularly vulnerable user group, careful user testing will be needed to evaluate the success of the device in assisting the user, along with the use of a minimum number of simple user interfaces to match the cognitive limitations of the individual. In the case of a progressive condition such as Alzheimer's disease, the device should automatically adapt over time as the user's cognitive impairment worsens. Current work along these lines could include approaches based on usability testing and simulations of actual situations with representative subjects with varying levels of cognitive deficit.

8.5.8 Promoting functional independence

One of the most promising areas where pervasive computing technologies can be used is in promotion functional independence. Here, the environment can adapt to the functional deficits of an individual who has compromised sensory motor function or has musculoskeletal disorders that have limited his or her ability to perform ADLs. In such cases, the individual is now able to control his or her environment using voice recognition.[31] The environment can also be contextually aware and can adapt to the individual's movements and needs as he or she moves from room to room, making proactive decisions about what the individual will want and responding appropriately.[32] For example, a wheelchair-bound individual can now move freely throughout his home without having to open doors or turn on lights, as these are automatically and preemptively controlled by the system. Such systems hold much promise to help individuals who have functional impairments to live longer in their own homes. Further development of these technologies is needed, as number of user-interaction issues remain to be fully explored. Some of these include (a) how a balance will be achieved between the "system's perceived importance of the interaction and the user's perception of the appropriateness of the interaction and level of intrusiveness of the event,"[33] (b) what constitutes the context appropriateness of the system's interaction with the user and how it will be determined, (c) how the user will control and judge the current state of the interaction (e.g., can the user cut short or disengage the system when his or her needs are fulfilled? can he or she easily move to another activity when he or she no longer needs to address the first activity? how does the user engage and disengage the system if there are dependencies between devices that have been networked?), (d) how the user judges functionalities that are being used for the first time, (e) how the user switches between different modes while engaged in an interaction sequence,[33] and (f) whether the individual wants a seamless interface with his or her home and how this affects quality of life.

8.6 Considerations for new and mixed modalities of interaction in pervasive healthcare

One of the greatest challenges in the design of usable and useful pervasive applications is the improved integration and appropriate application of varied modalities that are afforded by such systems. As argued earlier in this chapter, technological advances may have outpaced our understanding of the cognitive and perceptual aspects involved in the use of varied interface modalities. Healthcare has provided a unique and complex testbed for studying some of the more exciting technological advances in user interfaces.[34,35] Work in healthcare has also highlighted some of the major issues and barriers related to HCI that have restricted the adoption of pervasive technologies to date. The complex conditions that surround healthcare professionals (e.g., emergency rooms, operating rooms, the patient bedside, etc.) necessitate flexible modes of interaction with healthcare information systems. In particular, the issue of data entry by health professionals has been one of the biggest barriers to direct use of both conventional and pervasive applications. Although improvements have taken place in areas related to pen technology, handwriting recognition, PDAs, and wireless connections,[35] applications that require entry by pen or stylus are limited in the context of pervasive applications. Speech recognition solutions for data input into pervasive devices and for entering spoken commands to such systems are attractive, hands-off alternatives.[36,37] However, given the environmental considerations involved in many clinical activities (e.g., physician activities in a noisy clinical environment or emergency room), the use of speech input may be limited. Other than use in a private office setting, privacy concerns further limit the use of speech in many clinical contexts. Other types of interfaces, including head-mounted displays (HMDs), provide possible alternatives for appropriate healthcare applications.

Given the array of input and output options, work along the lines of developing user interfaces that allow for switching among different modalities of interaction is becoming an increasingly recognized area in design of user interactions with pervasive computing.[33] Advances in understanding how to integrate input modality into pervasive applications (e.g., by employing advanced workflow modeling techniques) will likely lead to improved models of interaction that allow for adaptive mixed modalities of interaction based on the contexts encountered by the healthcare professional. Along these lines, research from the area of adaptive user interfaces is extremely relevant to the issues that arise from user interaction with pervasive systems.[38,39] Adaptive technologies use intelligent approaches for modeling users, contexts, and user needs to help support a number of functionalities, including a number of different dialogue modes and the switching of modes in a way that is easy for the user to understand, learn, and interact with. Work in this area is conducted along several lines, including adaptive content selection by systems, adaptive navigation support, and adaptive presentation of information to users;[39] for example, providing physicians with particular medication guidelines specific to the hospital site where they are currently located. According to Perry et al.,[33] the central issues for developing adaptive approaches to pervasive systems include allowing for smooth transitions between modes and the ease of learning how to use different modes by users. In addition, issues related to context sensitivity include designing systems with location-appropriate interactions (i.e., systems that provide users with appropriate interactions given a particular location), activity-appropriate interactions (i.e., systems that provide users with appropriate interactions given a specific task or activity), and multiuser interactions, as well as appropriate assessment by the system for interaction (e.g., automated assessment of what interactions should take place and in what order or priority).

The difficulties of designing context-sensitive adaptive systems have been described elsewhere in this chapter but include the following: (1) the need for users to have a sense of control, (2) consistency across modalities as much as is possible through use of common semantics, and (3) appropriate switching between modes based on user needs, tasks, and locations. Complicating the development of such systems is the fact that target populations may be extremely varied (e.g., cognitively impaired older adults have varying levels and types of impairments), making the design of a "one size fits all" system for a particular class of users inappropriate. The development of effective pervasive systems in healthcare depends on the use of appropriate methods for guiding the design and testing of particular applications.

8.7 Discussion and conclusions

We have presented a number of different frameworks and methodological approaches for considering human factors of pervasive computing systems in healthcare. In addition, the application of a number of HCI methods to pervasive computing in healthcare has been discussed. We argued throughout that the success of these systems ultimately depends on how well they support and augment real workflow and human activities. A number of the issues related to human–computer interaction and pervasive computing system design are currently being explored in usability laboratories, such as the one we established for the analysis of new healthcare innovations. This has included study of systems ranging from CPR systems to PDA applications designed to provide context-sensitive access and presentation of information to a range of users including healthcare providers, patients, and laypeople. This has involved taking a "portable" approach to studying complex interactions with pervasive systems with recording equipment that can be taken into the actual settings where pervasive systems would be used. Work such as the projects described above has been focused on understanding how advanced HCI methodologies and techniques can be applied to improve the usability and usefulness of a range of healthcare systems including emerging pervasive applications.

The devices, systems, and concepts presented here highlight some applications of pervasive healthcare. Indeed, new pervasive healthcare technologies are already helping patients live longer and more independently. Some systems, such as the use of remote telemetry monitoring via telephone by nurses, have been developed to enable health professionals to remotely monitor patients, allowing patients to recuperate in the comfort of their homes without compromising their health and safety. No one particular area of pervasive computing in healthcare has experienced more growth than that of technologies aimed to assist with the unique sensory, cognitive, and functional concerns of the elderly and disabled.[40] A shift has taken place from providing patient care in the hospital to providing increasing levels of complex patient care in the community. With this shift a greater emphasis has been placed on individual patients and their families and health professionals. However, issues related to providing effective, robust, and usable applications that truly support users are likely to be the greatest barrier to the widespread adoption of pervasive healthcare applications. To overcome this challenge, careful design and extensive usability testing of new applications are required to ensure that applications meet user needs.

From the perspective of HCI, the complexity of providing information and support to both health professionals and patients on an "anytime and anywhere" basis is enormous. Only the use of principled theoretical and methodological frameworks from the field of HCI will meet this challenge. As discussed, developing system context sensitivity, adaptive system capabilities, and appropriate models of user interaction is essential for successful deployment of new pervasive technologies. The critical barriers from the human-factor dimension of healthcare systems need to be addressed from an interdisciplinary and flexible perspective. This includes developing methods of workflow analysis and new approaches to requirements data gathering, which will be used in conjunction with usability testing to lead to improved system designs and effective user interactions.

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