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Mobile Point-of-Care Systems in Hospitals: Designing for the Doctor-Patient Dialogue

Thesis for the degree of Philosophiae Doctor

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To Oskar Alsos (1937 – 1994)

Abstract

Background: Doctor-patient communication is important for the treatment and care of patients. It has a significant effect on patient outcomes, such as their satisfaction, adherence to treatment, understanding of information, and health outcome. Physicians' use of stationary computers can have a negative impact on doctor-patient communication. There is, however, little knowledge on the effects of physicians' use of mobile point-of-care systems on doctor-patient communication. There is also little knowledge on how to design and evaluate mobile systems that support this important doctor-patient dialogue.

Aim: The overall research aim was to explore the properties of mobile point-of-care systems in hospitals that are important for doctor-patient communication in ward rounds. The following research questions were answered:

(1) How do mobile point-of-care systems affect doctor-patient communication in ward round settings?
(2) How should mobile point-of-care systems be designed to support the doctor-patient dialogue?
(3) How should usability evaluations of mobile point-of-care systems be planned and conducted to maximize the value and validity of the results?

Method: The study was based on four realistic usability evaluations of mobile point-of-care systems. The evaluations were conducted in a simulated hospital ward, where 36 physicians and/or nurses performed 180 ward rounds with patient actors. Video and interview data were analyzed using techniques from qualitative video analysis and grounded theory.

Contributions: The following empirical contributions were found:

(1) The effects of mobile point-of-care systems on doctor-patient communication, for example how the systems affect verbal and non-verbal communication.

(2) Guidelines for designing mobile point-of-care systems that support doctor-patient communication, i.e. how the user interface and form factor should be designed and how designers should think.
(3) Methods to maximize value and validity of usability evaluations with doctors and patients, for example how to record the evaluations, how to encouraging and capture user reflection, and how to frame the research design with "just enough" simulation fidelity.

Conclusions: Mobile point-of-care systems in ward rounds can have an impact on the verbal and non-verbal aspects of doctor-patient communication. Physicians and other health care professionals using such systems should be aware of this impact and take necessary measures to avoid negative effects. However, doctor-patient communication is more than the communication skills of the physician. It can also be supported by good system interaction design and smart device form factor design. Therefore, designers need to broaden their perspective and design for doctor-patient communication. Furthermore designers need to improve the value and ecological validity of usability evaluations with enhanced recording techniques, find better ways of promoting user reflection than at present, and introduce evaluations with just enough realism.

The findings can have relevance for researchers within Health Informatics, Medicine, Human Computer Interaction (HCI) and Computer Supported Collaborative Work (CSCW), designers and developers of mobile point-of-care systems, as well as clinicians and patients.

Preface

I found my Computer Science studies interesting and varied, with a broad number of topics and sub-disciplines. However, after my first lecture in Human Computer Interaction, I immediately knew that this was the field I wanted to study – this was the field where I wanted to become a professional.

After finishing my master's thesis (and actually enjoying it), I started working as a usability professional in an IT consulting company. I enjoyed the work, but felt there was a conflict between helping the customer to make user-friendly solutions and making money for the company. The first was by far the most rewarding for me.

When my former supervisor announced an open PhD position at NTNU, without customers to bill, no hours to log, and with a higher meaning than the company earnings, I could not resist applying. The research project I was hired into was called POCMAP (point of care multi-aware clinical pilot). It aimed at developing the next generation of mobile point-of-care systems. It was funded by the Research Council of Norway[1], DIPS ASA, the Industrial Research Fund for NTNU, St. Olav University Hospital, Akershus University Hospital and the Norwegian University of Science and Technology. In addition, travel grants were provided by the Norwegian Technical University Fund and the Norwegian Research Centre for Electronic Patient Records. The project was managed by Associate Professor Øystein Nytrø at the Department of Computer and Information Science, NTNU. I was supervised by Professor Dag Svanæs at the Department of Computer and Information Science, NTNU, and co-advised by Associate Professor Arild Faxvaag at the Faculty of Medicine, NTNU.

This thesis represents some of the work I have accomplished since I started my PhD project in 2007.

[1] Grant 176761 (POCMAP) of the VerdIKT program

As a person with passion for the simple and user friendly, I have attempted to make this thesis as reader-friendly as possible. This has been the most difficult task, and only the reader can judge if I have succeeded.

Looking back, I have found the years at NTNU as a PhD candidate rewarding, both on the personal and professional levels. The hard times are just a faint memory.

Acknowledgements

This thesis could not have been written without the help and support from a number of people. First of all I am grateful to my supervisor, Professor *Dag Svanæs* at the Department of Computer and Information Science (IDI), for guiding me through the journey of completing a PhD thesis, for sharing his knowledge, and for collaborating with me on several research papers. Secondly, I wish to thank Associate Professor *Arild Faxvaag* at the Faculty of Medicine (DMF) for being an excellent co-advisor and collaborator, as well as for helping me get a medical perspective on the research.

Special thanks go to *Benjamin Dabelow*, whom I co-advised during the writing of his master thesis. His excellent, high quality work has been the basis for several of my research papers and follow-up studies. Special thanks also go to *Yngve Dahl* at Sintef, whom I have collaborated with on a number of research papers, and who have given me valuable feedback on my thesis. I also thank *Anita Das* at DMF, who have co-authored a paper with me, and *Terje Røsand*, a highly skilled technician at the Norwegian Research Centre for Electronic Patient Records (NSEP) who have made things work in the usability laboratory.

In the POCMAP project I have had the joy of collaborating with Associate Professor *Øystein Nytrø* at IDI who was co-advising me in the early stages of my thesis work, and *Gry Seland* and *Inger Dybdahl Sørby*, who have been sharing their knowledge and experience with me, both as PhD-students and parents. Thank you.

In addition there have been a number of people that have supported me: Thanks to all my colleagues at IDI and NSEP for helping me with large and small administrative, technical and practical issues during these years and for making my days enjoyable; to *Aksel*, *Line*, *Erna*, *Christian*, and *Paul* for introducing me to the mystical world of sociology; to *Monica* and *Pieter* for giving me feedback on parts of the work; to all the members of *Forskerfabrikken* ("The Scientist Factory"), *Børge, Eric*, *Gasparas*, *Geir Ketil*, *Gro Alise*, *Kirsti, Thomas, Tor Erlend*, *Torgeir*, *Torstein*, *Vigdis*, and *Øyvind,* for the professional fellowship, knowledge sharing and cake eating; to all the anonymous *test subjects* that participated in my studies; to all the *international senior researchers* that have given me advice in various doctoral colloquiums and other settings; and to *Stewart Clark* at NTNU for editing Part 1 of this thesis.

I wish to express my gratitude to all my dear *family* and my lovely *friends* for giving me an interesting and rich social life when I have not been busy working on the thesis.

Most of all, I thank my wonderful family for support, baby-sitting, and proof reading. My dear *Ida*, *Andreas*, *Erik*, *Hergunn*, *Kari*, *Lars* and *Eli* – without you this could not have been possible.

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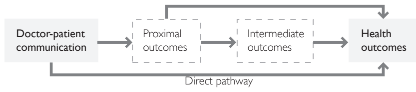
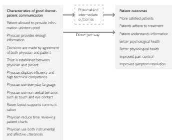
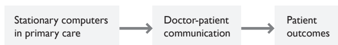
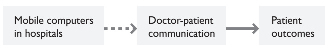
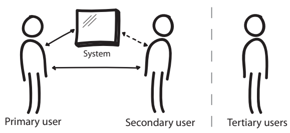
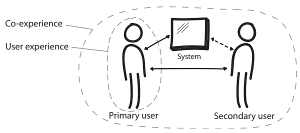




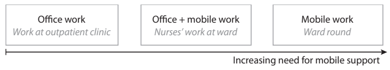









Smart phone
PDA
Laptop on wheels
Patient terminal
Tablet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Mobile work
Ward round
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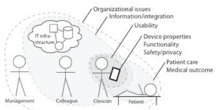
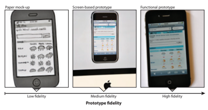
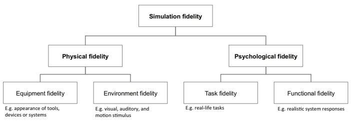
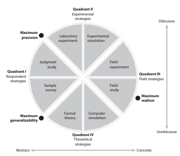


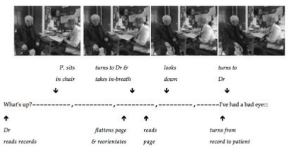


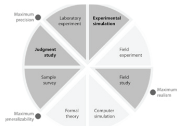

Lab-based usability evaluations
Field evaluations
Increased control (less realism)
Increased realism (less control)

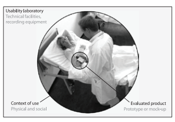

Lab-based usability evaluations
Simulation-based evaluations
Field evaluations
Increased control (less realism)
Increased realism (less control)

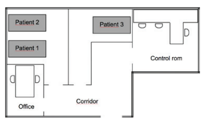

Simulation fidelity
Physical fidelity
Psychological fidelity
Equipment fidelity
Environment fidelity
Task fidelity
Functional fidelity

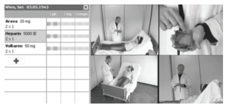


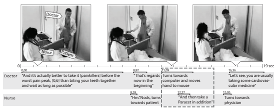


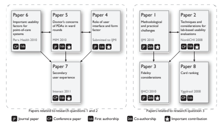


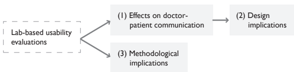



Patient 2
Patient 3
Patient 1
Control rom
Office
Corridor








Lab-based usability evaluations
(1) Effects on doctor-patient communication
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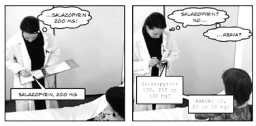
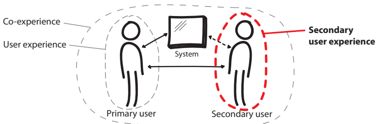
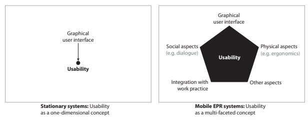
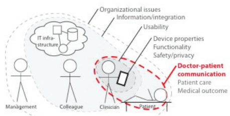
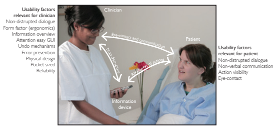
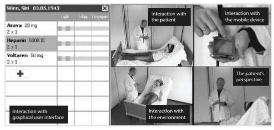



Co-experience
User experience
System
Secondary user experience
Primary user
Secondary user










a
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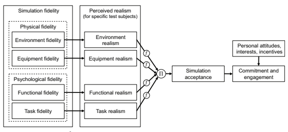
Simulation fidelity
Physical fidelity
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Part I

Introduction and Synthesis

1. Introduction

From the dawn of modern medicine, the medical consultation has been the key for doctors to diagnose and treat patients successfully. A number of patient outcomes, such as satisfaction, adherence to treatment, information recall and understanding, are affected by the communication with the physician, and effective doctor-patient communication is shown to have positive effects on both psychological and physiological health (Ong et al., 1995, Stewart, 1995).

In the early days of modern medicine, paper-based medical records provided the clinicians with necessary information about the patient during ward rounds in hospitals. Today, new technologies, with amazing possibilities and opportunities that were unbelievable a few decades ago, are about to replace many of these paper-based tools. Mobile health care systems now allow clinicians to access patient records, knowledge bases, procedures, and medication databases at the *point-of-care* – bedside, where the patient is.

However, the new technology faces their users and developers with a number of new challenges. Research from primary care show that computer usage in the patient consultation can hamper the communication between doctors and their patients, which may have negative effects on the patient's satisfaction and health. There is still little knowledge about how the *mobile* point-of-care systems affect this communication.

Today we already have the knowledge and methods to make efficient and user-friendly desktop-based health care systems for the clinicians. However, when the systems go mobile, the *context of use* becomes increasingly complex as the hospital is an event-driven and communication-intensive working environment with constant interruptions and parallel tasks. Many of the existing mobile systems have failed to support this context of use, and demand a too large share of the users' time and attention. This can cause stress for the clinicians and increase the probability of medical errors, incomplete medical records and lost information. In all this, there is the patient, who may also be affected by the usage. The mobile systems might become a third party in the ward round that requires a significant share of the clinicians' attention. This can hinder effective communication with the patient, causing negative effects on the patient's satisfaction and health, as this scenario illustrates:

> *John, 25 years old, is hospitalized after a serious climbing accident. He has broken several ribs and suffers from compression fractures in his back. After nearly two weeks in hospital he is improving, but last night he experienced fever and shortness of breath. This morning senior physician Sarah Smith sees him during the daily ward round. She is using a laptop on wheels to provide point-of-care access to the electronic patient record, and informs him about the latest results from the radiograph. From John's point of view, he cannot see what she is doing, but she looks very busy and seems to be very focused on the laptop screen. Although he wanted to talk to Dr. Smith about his condition this morning, John is worried that he will disturb her. When Dr. Smith eventually signals that she needs to move on to the next patient, it is too late. John fails to bring up his breathing problems.*

The above scenario illustrates some of the negative effects that mobile technology can have on doctor-patient communication. How should we design mobile point-of-care systems that support the dialogue between the clinician and the patient?

When designing and developing health information systems there are a number of established processes and methods that are applied to ensure efficient and user-friendly systems. One such method is *usability evaluation*. Being one of the most effective ways to discover usability problems and inform system design, this method is often applied in various stages of the software development process. When evaluating the usability of software for a single physician in typical desktop situations it is fairly simple and straightforward to reproduce the context of use in a lab setting. However, when moving into mobile use contexts in the hospital where both patients and colleagues are present, the evaluations become increasingly complex. Literature offers immature directions on how to conduct usability evaluations of mobile point-of-care systems with multiple users and stakeholders, and there are few guidelines on how to deal with ecological validity and other methodological issues in such contexts.

This thesis is about (1) understanding how the doctor-patient communication is affected by the mobile systems, (2) examining how to design such systems to support the dialogue rather than disturb it, and by this (3) improving the methods used to design and evaluate systems that are used in a ward round setting.

1.1. Research aim

Given the challenges above, the overall research aim for this thesis is to **explore the properties of mobile point-of-care systems in hospitals that are important for doctor-patient communication in ward rounds.**

Limitation of scope (framing)

The scope of this thesis is limited by focusing mainly on mobile computerized physician order entry systems (CPOE), where the physician can prescribe and change the patient's medications in ward round situations. This excludes mobile phones and callers. It also excludes stationary computers. Bedside terminals are included, as they allow clinicians to access the information systems at the point of care. Throughout the thesis I use both the terms *mobile point-of-care systems* and *mobile electronic patient record systems*. While the latter actually is a subset of the former, I use both terms for a system that provides clinicians with information about the patient or allows them to add or change information.

Research questions

Given the research challenges and aim above, the following research questions are formulated:

(1) How do mobile point-of-care systems affect doctor-patient communication in ward round settings?
(2) How should mobile point-of-care systems be designed to support the doctor-patient dialogue?
(3) How should usability evaluations of mobile point-of-care systems be planned and conducted to maximize the value and validity of the results?

1.2. Research design

A number of different research strategies have been applied to the research conducted, such as surveys, interviews, field studies, focus groups, design workshops, and role play workshops. The main method of this thesis is simulation-based usability evaluations. Four evaluation studies of different mobile health care systems have been conducted by myself and/or my colleagues at the *Department of Computer and Information Science* and the *Norwegian Electronic Health Record Research Centre*, both at the *Norwegian University of Science and Technology* in Trondheim, Norway. In these studies clinicians have performed bedside patient consultations in a simulated hospital ward while using different mobile prototype systems to make changes in the patients' electronic patient record (Figure 1). After the evaluations, clinicians and patients have been interviewed about different aspects of how they experienced the EPR system in use.

It is important to note that the design of some of the above-mentioned evaluations was originally intended for other purposes than the aims of this thesis. The overall aim for these evaluations was to identify usability problems for specific mobile point-of-care systems. This thesis is a retrospective analysis of the empirical data from these four usability evaluation studies. The data were analyzed using qualitative video analysis techniques from sociology, and an approach inspired by grounded theory.

Figure 1. The research design is based on simulations of hospital scenarios in a usability laboratory designed as a full-scale model of a hospital ward.

1.3. Contributions

This thesis is based on eight papers that are published in international journals or peer-reviewed conference proceedings. The main contributions in these papers are:

(1) Assessment of effects of mobile point-of-care systems on doctor-patient communication.
(2) Guidelines for designing mobile point-of-care systems that support doctor-patient communication.
(3) Methods to maximize the value and validity of lab-based usability evaluations of mobile point-of-care systems.

The outcomes have implications for how we think about, design and evaluate mobile point-of-care systems in hospitals. This means that the contributions are relevant for (1) *researchers* within Health Informatics (HI), Medicine, Human Computer Interaction (HCI) and Computer Supported Collaborative Work (CSCW) (2) *designers* and *developers* of mobile point-of-care systems, and (3) *clinicians* and *patients* in hospitals.

1.4. Thesis overview

This thesis consists of two independent parts:

- **Part I** presents the introduction to this work, and gives an overview of the background, the methods used, the results achieved, and the contributions and implications of this thesis.
- **Part II** includes eight research papers that present the results of this thesis.

The rest of **Part I** is organized as follows:

- **Chapters 2, 3 and 4** give an overview of the literature that is relevant for the argument presented in this thesis. *Chapter 2* introduces knowledge on the impact of computers on the doctor-patient dialogue, while *Chapter 3* presents current knowledge on mobile electronic patient record systems in hospitals. *Chapter 4* expands on usability evaluations of mobile technology in health care.
- **Chapter 5** outlines relevant research strategies for conducting research on doctor-patient communication and mobile point-of-care systems.
- **Chapter 6** describes the methodological approach taken and relates the four usability evaluation studies conducted to the eight research papers.
- **Chapter 7** summarizes the research papers, which present the results of the thesis.
- **Chapter 8** discusses the findings and limitations of the thesis, and suggests research areas where future efforts could be focused.
- **Chapter 9** concludes this thesis.

Part II contains the eight research papers in full length. For easy referencing throughout the thesis, the papers are numbered and given a descriptive short title. Throughout the thesis, references to the papers are done in-text by paper number and/or short title, together with its page number in the thesis when appropriate (e.g. *Paper 3 – Fidelity considerations, pp. 998-9).* The relations between the papers and the research contributions are presented in Table I.

Paper 1. Methodological and practical challenges.
Svanæs, D., Alsos, O. A., Dahl, Y. *Usability testing of mobile ICT for clinical settings: Methodological and practical challenges*. International Journal of Medical Informatics, *79*(4), 2010, Elsevier.

Paper 2. Techniques and considerations for lab-based usability evaluations.
Alsos, O. A., Dahl, Y. *Toward a Best Practice for Laboratory-Based Usability Evaluations of Mobile ICT for Hospitals*. Proceedings of NordiCHI 2008, ACM.

Paper 3. Fidelity considerations.
Dahl, Y., Alsos, O. A., Svanæs, D. *Fidelity Considerations for Simulation-Based Usability*

Assessments of Mobile ICT for Hospitals. International Journal of Human Computer Interaction, *26*(5), 2010, Taylor & Francis Group.

Paper 4. Role of user interface and form factor.
Alsos, O. A., Das, A., Svanæs, D. *Mobile Health IT: The Role of User Interface and Form Factor on Doctor-Patient Communication and Collaboration.* To appear in International Journal of Medical Informatics (accepted 13 September 2011).

Paper 5. Effects of mobile devices in ward rounds.
Alsos, O. A., Dabelow, B., Faxvaag, A. *Doctors' concerns of PDAs in the ward round situation: Lessons from a formative evaluation study.* Methods of Information in Medicine, *50*(2), 2011.

Paper 6. Important usability factors for point-of-care systems.
Alsos, O. A., Dabelow, B. *A Comparative Evaluation Study of Basic Interaction Techniques for PDAs in Point-Of-Care Situations.* Proceedings of PervasiveHealth 2010, IEEE.

Paper 7. Secondary user experience.
Alsos, O. A., Svanæs, D. *Designing for the Secondary user experience.* Proceedings of Interact 2011, Springer.

Paper 8. Card ranking.
Alsos, O. A., Dahl, Y. *Ranking for Reflection: The Application and Added Value of Picture Cards in Comparative Usability Testing.* Presented at Yggdrasil 2008 [available at http://bit.ly/paper8].

Table I. The relation between research papers and research questions.

	Research papers							
Research questions	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
(1) Effects of mobile systems on doctor-patient communication				•	•	•	•	
(2) Designing guidelines for mobile point-of-care systems				•	•	•	•	
(3) Methods for lab-based usability evaluations	•	•	•				•	•

2. Doctor-Patient Communication

In the introduction, doctor-patient communication was presented as an important part of effective patient treatment. The aim of this chapter is to present current knowledge on communication between doctors and patients, and show how stationary and mobile computers used in consultations can both support and hinder this communication. The chapter also discusses the concepts *awareness* and *affordance*, and highlights their importance for the doctor-patient dialogue.

2.1. Communication

Communication has played an important part in the evolution of the human society as we know it. In addition to the semantic structure and content of the spoken word, turn-taking, gaze and eye-contact are fundamental components of communication.

Turn taking

The process of organizing conversations is called turn taking, and is mainly studied in the social sciences. The purpose is to avoid silence or overlaps in the dialogue, or to repair it when something is misunderstood or overlaps occur.

The right to speak in conversation is commonly referred to as 'the floor'. The cues used to take or give up the floor can be rather subtle. These signals can be *implicit*, such as body language, gaze, tone of voice, or *explicit*, using linguistic features such as clauses, suggestions, requests or questions (Sacks et al., 1974).

Similarly, different techniques can be used in conversation *openings* or *closings*, i.e. how to start or close a conversation. For both, *verbal behavior*, such as appreciations or external legitimizations, or *non-verbal behavior*, such as establishing or breaking eye contact, or moving towards or away from the converser, are examples of such techniques (Kendon and Ferber, 1973; Knapp et al., 1973). A typical example from medical consultations is how doctors initiate closings by handing over a prescription to the patient while informing that "You can take it down to reception" (Heath, 1986).

Gaze and eye contact

Gaze and eye contact are important components of communication. These are closely linked to the spoken word and are used in turn taking to synchronize talk. In addition, gaze provides additional non-verbal information that can elaborate and modify the verbal message. Moreover, gaze shows that a person's attention is directed on another person, and it displays interest and gives feedback on how others are reacting. People who look more at their conversant are perceived as more attentive, while those who fail to look indicate lack of interest. The need for mutual gaze increases with distance because the resolution of the non-verbal feedback channel is decreasing (Argyle and Cook, 1976).

2.2. The importance of the doctor-patient dialogue

Communication between the doctor and patient is an important element of medical treatment and care. Coiera (2000) points out that communication errors cause twice as many deaths as inadequate clinical skills, while Bhasale et al. (1998) show that 23 percent of all adverse events detected in a primary care study were associated with communication difficulties between the physician and the patient.

According to Ong et al. (1995), doctor-patient communication has three main purposes: (1) To create a good inter-personal relationship between the physician and the patient, (2) to exchange information between the doctor and the patient, and (3) to make decisions about medical treatment. In hospitals, this communication is often done during *ward rounds*, where the physician visits the patients in their hospital beds.

A ward round can be viewed as a collaborative effort between the patient and clinicians: During the ward round the patient has the opportunity to tell their story, ask questions, and get information. The round is one of the most important settings for the physicians to get first-hand information about the patient. Through the ward-round dialogue multiple aspects unfold. Thus social, psychological, and medical aspects as well as practical issues are often discussed. Through this information exchange, many decisions about patient care are made. By letting the patient tell his/her story, the physicians can interpret this information, and further discuss this with the team of health care professionals. Physical examination at the bedside is also an important part of the round. In addition, the clinicians have the opportunity to register important information in the patient chart, order tests, or prescribe new medication.

Communication is a vital part of patient treatment and care (Ong et al., 1995; Roter and Hall, 2006). Medication errors and problems with delivering care can be rooted in communication difficulties between the doctor and the patient (Beck et al., 2002; Levinson et al., 1997; Woolf et al., 2004). In contrast, good doctor-patient communication leads to a number of improved patient outcomes, such as improved adherence (Zolnierek and DiMatteo, 2010) and improved health outcomes (Cegala et al., 2000; Stewart, 1995; Ong et al., 1995). Improved emotional health, symptom resolution, better function, improved physiological measures, and pain control are other examples of patient outcomes discovered (Stewart, 1995).

2.3. Patient outcomes of good doctor-patient communication

Patient outcomes are any effects of medical treatment on the patient. A number of studies have shown positive patient outcomes from good doctor-patient communication. Ong et al., (1995) categorize patient outcomes as (1) the patient's satisfaction, (2) adherence to treatment, (3) understanding of information, and (4) health outcome. Below, some findings related to the four categories of patient outcome are shown.

Satisfaction

Patient satisfaction can be viewed as a measure of the quality of health care services from the patient's point of view (Fitzpatrick, 1984). Research has pinpointed a number of important factors that affect the patient satisfaction:

- Patient satisfaction is related to the amount and quality of information the doctor gives to the patient (Roter and Hall, 1989; Roter et al., 1987).
- The medical interview length is positively related to patient satisfaction (Smith et al., 1981).
- Increasing time by physicians reviewing the medical chart has a negative impact on patient satisfaction (Smith et al., 1981).
- The physicians' socio-emotional behavior, such as eye contact and showing interest, is an important factor for patient satisfaction (Bensing, 1991; Buller and Buller, 1987).
- Physicians' spatial closeness to the patient is also shown to affect patient satisfaction (Larsen and Smith, 1981).

Adherence to treatment

Patient adherence is the extent to which patients follow the recommendations of their health care professional. Drawing on 127 studies of how physicians communicate with their patients, Zolnierek and DiMatteo (2009) found that patient adherence is significantly related to the physicians' communication skills, and that adherence can be improved by training physicians in communicating with their patients. The meta-analysis showed that patients of physicians with good communication skills had 19% higher adherence. Moreover, by training physicians' ability to talk with patients, adherence improved by 12%. The authors also suggest that this ability is particularly important in pediatric care and when the experience and medical skills of the physician is low.

Understanding of information

Patients often have difficulties understanding and remembering what the physician has told them (Ley, 1988). In a study from primary care up to half the patients did not understand the diagnosis and prognosis of the disease. Moreover, they were only able to recall between 40 and 80% of the information they received (op. cit.).

Close physical proximity or immediacy has shown to increase the patients' understanding of diagnosis and prognosis (Smith et al., 1981; Larsen and Smith, 1981). Giving the patient more information can also increase information recall (Roter et al., 1987). A meta-analysis suggests that the doctors' communication skills may have an effect on patients' ability to remember the information given (Roter and Hall, 1989).

Health outcomes

A number of studies suggest that patient health outcomes can improve with good doctor-patient communication, both on psychological and physiological levels. In a literature review, Stewart (1995) found that the health outcomes of doctor-patient communication include improved emotional health, symptom resolution, better function, improved physiologic measures, and better pain control. For example:

- Patients who were instructed by their physician about postoperative pain and how to control it, had lower pain levels, used less narcotics, and had shorter hospital stays than control subjects (Egbert et al., 1964 cited in Stewart, 1995).
- Improving communication with patients with various medical problems (e.g. breast cancer or diabetes) significantly improved patients' health status, functional status, and physiological measures, such as lower blood pressure and better glucose level (Kaplan et al., 1989).
- Cancer patients who were given extra detailed information about radiotherapy showed less emotional disturbance than the control group (Rainey, 1985).

Despite many positive effects, a good dialogue between doctors and patients is not a guarantee for positive health outcomes. There are studies that have found no correlation between doctor-patient communication and health outcomes. For example, in a randomized control trial, physicians were trained in communication with diabetes patients. Although patients reported improved satisfaction with respect to communication and better well-being, the intervention had no effect on their metabolic control. In fact, these patients gained more weight than the control group (Kinmonth et al., 1998).

The pathway from a good doctor-patient dialogue to positive health outcomes is not always obvious. Street et al., (2009) argue that there are both direct and indirect pathways from communication to health outcome (Figure 2). An example of a direct pathway is when the dialogue with the doctor has a therapeutic effect on the patient (e.g. improved psychological health). This is what is usually measured. However, in most cases there is an indirect pathway between communication and outcome. For example, good communication can lead to *proximal outcomes*, such as satisfaction, trust and motivation. The proximal outcomes can lead to *intermediate outcomes*, such as improved adherence and self-care skills. The intermediate outcomes can lead to the observed health outcomes, such as pain control or improved psychological health.

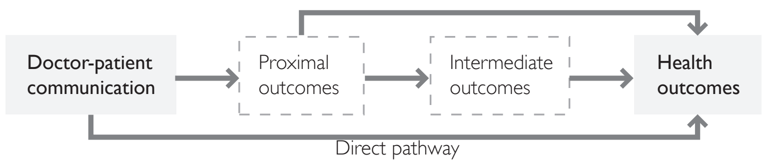

Figure 2. Good doctor-patient communication can lead to positive health outcomes, either directly or via proximal and intermediate outcomes (adapted from Street et al., 2009).

2.4. Defining the "good" doctor-patient communication

Researchers have put considerable effort into understanding the importance and characteristics of good doctor-patient communication. This understanding has for example been used in the education of medical students (Roter and Hall, 2006). Below, some of these characteristics are summarized. This summary is not complete, but focuses on the most important aspects that may be relevant for the design of a mobile EPR system supporting doctors in their meetings with patients.

Information exchange

From a medical point of view physicians need information from patients in order to infer correct diagnosis and to create a treatment plan. Because of time pressure and high workload, physicians often want to make the information gathering as time efficient as possible. Unfortunately, patients are often interrupted when describing problems to the doctor – so often that they fail to describe other important medical problems and concerns (Beckman and Frankel, 1984). This implies that patients should be allowed to tell their story without being interrupted (Simpson et al., 1991).

From the patients' point of view, they need to know why they experience the medical problems, what significance the problems have for them. They also "need to feel known and understood" (Ong et al., 1995). In general, patients have a strong need for information, but physicians often underestimate this need (Blanchard et al., 1988). This implies that the health care professionals should take the time to give the necessary information.

Shared decision making

Shared decision making is when the decisions are not only taken by the health care professional, but when also the patient is involved in information sharing, consensus making, and treatment planning and implementation (Charles et al., 1997). Shared decision making is an important element of good doctor-patient communication (Stewart, 1995), and patients who take an active part in decisions about treatment and care are shown to have better health outcomes (Greenfield et al., 1988; Kaplan et al., 1989 cited in Elwyn et al., 1999).

Trust

Patient trust is a key component of good doctor-patient communication (Wright et al., 2004; Graham et al., 2010). Trust has been defined as the expectation of the patient that physicians prioritize the patient's best interest (Hall et al., 2001). Because of the asymmetrical relationship between the doctor and patient, trust is important for a patient's willingness to visit a health care professional, and to follow his/her advice. Lack of trust can therefore have serious consequences for the patient's health status.

Technical competence and efficiency

Patients judge their physician's competence by their technical behavior and proficiency (Hall et al. 1988). For example, a physician who is clumsy or cannot adequately use the blood pressure gauge will be judged as having a low level of competence by the patient. Moreover, patients prefer physicians who display confidence and efficiency, and who are organized and make things happen (Wright et al., 2004).

Use of language

Doctors speak both *everyday language* and *medical language*, while patients are usually unfamiliar with medical language (Ong et al., 1995). The use of medical language in the doctor-patient dialogue may therefore be a source of communicational problems for the patients (Bourhis et al., 1989). Examples of medical language use are "scapula" instead of "shoulder blade", or "cessation of Selo-Zoc" instead of "stop taking the drug against migraine".

Practice of non-verbal behavior and eye contact

In medical research there is a strong focus on the verbal aspects of communication. However, only a small fraction of emotional communication is conveyed verbally (7%). Much is communicated through voice tone (22%) and body language (55%), such as eye contact, body position, facial expressions, physical distance etc. (Bensing, 1991). The non-verbal aspects are considered essential for the good doctor-patient communication. Examples of types of behaviors used in studies of non-verbal communication are physical proximity, time used on chart reviewing, and how much the physician looks at the patient (Smith et al., 1981; Bensing, 1991).

Eye contact is important in doctor-patient communication. Physicians who gazed frequently at the patient were more successful in recognizing psychological distress (Bensing et al., 1995). In addition, eye contact enhances listening skills and makes physicians more effective in reading emotional cues (Roter and Hall, 2006).

Physical room layout

The physical orientation of the physician related to the patient (and the EPR system) have an impact on nonverbal communication in medical interviews (McGrath, 2007). In particular do spatial room organizations that hinders eye contact have a negative influence on the doctor-patient dialogue.

Time spent reviewing patient charts

Higher patient satisfaction is associated with shorter time spent by the physician on patient chart reviews (Smith et al., 1981). This suggests that physicians should reduce their use of the patient chart during the consultation, but instead familiarize themselves with the information content before meeting the patient.

Instrumental and affective utterances

Instrumental (task focused) utterances include behavior such as providing information, asking questions and discussing lab results. *Affective* (socio-emotional) utterances include behavior such as being encouraging, relaxed, friendly, open and honest, and introducing oneself to the patient (Blanchard et al., 1983; Roter et al, 1991). Although the literature has mainly focused on instrumental behavior, researchers agree that both are important in establishing a doctor-patient relation (Ong et al., 1995).

Connecting communication and outcomes

Although it is only a simplified view, Figure 3 gives a summary of characteristics of good doctor-patient communication and links to health outcomes. Reviewing existing literature has not allowed me to confidently make a direct mapping between specific characteristics and specific health outcomes, as there are a number of proximal and intermediate outcomes between the characteristics and the patient outcomes. However, what Figure 3 illustrates, is that *improving the aspects of the doctor-patient communication implies improved patient health outcomes.*

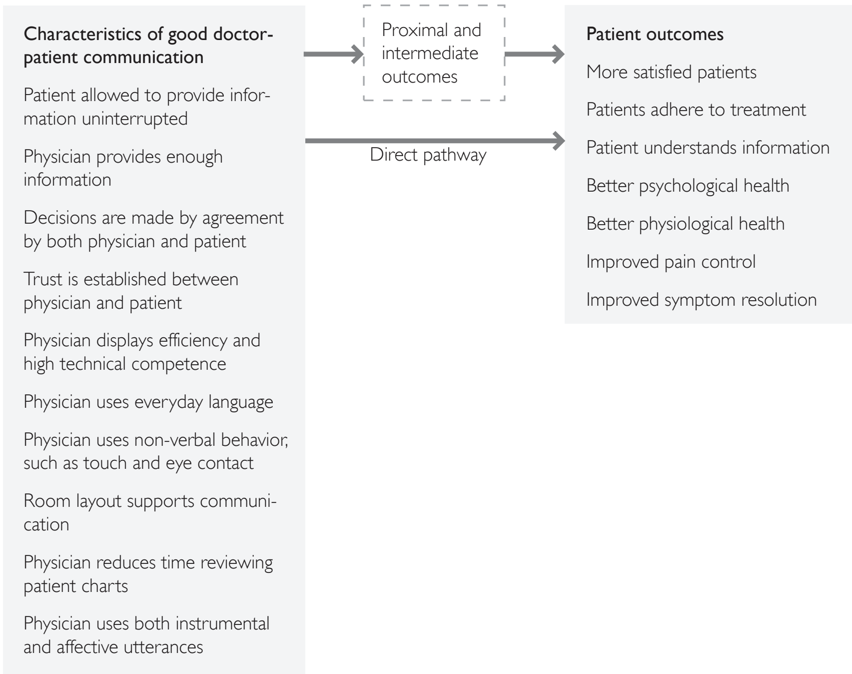

Figure 3. The effect of doctor-patient communication on patient health outcomes is through direct or indirect pathways. Both can be decomposed into a number of characteristics.

2.5. Effects of computers on doctor-patient communication

An electronic patient record (EPR), also known as electronic health record (EHR) or electronic medical record (EMR)[2], is the collection of information about plans and objectives for patient care, documentation of the delivery of care, and documentation of the outcomes of care. (Häyrinen et al., 2008).

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[2] The meaning of EPR is vague. Waegemann (2003) presents 10 different terms and sub-terms for electronic patient records.

Many countries have abandoned paper-based patient records and adopted EPR systems running on stationary computers in primary care and hospitals (Lærum et al., 2001; Protti and Johansen, 2010). Extensive research has demonstrated significant positive economic and medical effects of EPR usage (e.g. Uslu and Strausberg, 2008). In contrast, little research has been done on the psychosocial effects of EPRs, despite the fact that the impact of the computer on doctor-patient communication is increasingly questioned (Pearce et al., 2008). Some of the existing evidence indicates that the introduction of computers into the consultation has a significant negative impact on communication between patients and doctors (Margalit et al., 2006; Greatbatch et al., 1995). In this subsection some findings related to effects of computer usage on communication between doctors and patients are presented. To support comparison I use the same characteristics of good doctor-patient communication as in the previous subsection. Some of the characteristics have not been described in the literature, and are therefore omitted (e.g. “trust” and “use of language”). Other characteristics are specific for computers or modified to fit the new medium.

Information exchange

The use of computers in the patient consultation has shown to have both positive and negative effects on information exchange between the doctor and patient. On the one hand, the use of electronic patient records will often have a positive impact on information exchange, as the physician has both more and updated information available (Shachak et al., 2009). In addition, because the physician has more information available, EPR use is shown to correlate with better physician explanations of diagnoses and treatments by the physician (Hsu et al., 2005).

On the other hand, computer usage has resulted in both patients and doctors contributing less to the medical dialogue, something that “may inhibit sensitive or full patient disclosure” (Margalit et al., 2006). In addition, EPR use can disrupt the way patients explain their illnesses (Patel et al., 2002). Even if physicians using EPRs take a more active role in clarifying specific information, asking questions, and ensuring the completeness of the record, they are less likely to explore psychosocial/emotional issues such as how health problems affect a patient’s everyday life (Makoul et al., 2001).

Shared decision making

Computers can enhance shared decision-making and increase the patients’ participation in and control over the health care process (Weaver, 2001). Further, computer tools can offer patients information about treatment alternatives and health care options, and help them decide among them.

Technical competence

When computers are used in medical consultations, it can be hard to distinguish between technical proficiency and medical knowledge. Physicians are worried that computer inefficiency may lead to loss of control and authority in the consultation room (Chen et al., 2011). The success of computers is often related to the computer skills of the health care personnel; good skills often mean better communication with the patient (Frankel et al., 2005).

Affordances and physical room layout

Luff and Heath (1998) praised the *micro-mobility* of paper records, which "assist the communicative flexibility" of the medical consultation. In contrast to the computer, the paper record can easily be repositioned so as to let the patient view it, and it can easily be the focus of gestures and remarks. Even though the computer monitor can be turned towards the patient, it is hard to find a spatial configuration that supports communication and gives the patient equal access to information.

McGrath et al. (2007) found that the physical orientation of the physician related to the patient and EPR had an impact on non-verbal communication in medical interviews. The study identified three different office spatial designs; (1) '*open*', which allowed the physician to easily (re)establish eye-contact with the patient during EPR usage, (2) '*closed*', where no eye-contact was possible during use because of the position of the computer screen, and (3) *'blocked'*, where the computer screen or distance to the patient hindered eye contact.

The use of *computers on wheels*, which are movable within the office (i.e. not mobile), allows the physician to shift between *exclusive viewing*, where the computer is faced the physician, *collaborative viewing*, where the physician and patient view the information together, and *neutral viewing*, where the computer screen optionally can be viewed by the patient (Chen et al., 2011). However, the use of such computers increases the spatial proximity between doctors and patients, which hinders the dialogue.

Time spent using the EPR

In an observational study, Heath (1986) analyzed patient consultations where the paper-based medical records were replaced by EPRs on stationary computers. Both the medical records and the EPR appeared to disrupt the patient's activities, and it was observed that the patient tried to attract the physician's attention by withholding speech with gestures and body movements until eye contact was re-established. However, unlike the paper record, the EPR demanded more of the physician's time and attention, thus interrupting the patient consultation more. In another observational study Margalit et al. (2006) found that one-quarter of patient consultation time was spent using the EPR.

Patient satisfaction

The use of computers in the consultation room influences how patients perceive the quality of the consultation (Dragnonge et al., 2006; Frankel et al., 2005). Although much evidence suggests that computers do have a negative effect on doctor-patient communication (e.g. Margalit et al., 2006; Bensing, 1991), there are studies that do not find any differences, or even point to improvements in elements of the doctor-patient dialogue. For example, Brownbridge et al. (1985) found that contrary to many doctors' concerns no overall negative effects were recorded for patient satisfaction. Moreover, the study claims that patients' satisfaction to the consultation are more affected by which doctor they see than by whether or not the doctor is using a computer.

Another study found no decrease in patient satisfaction when an EPR was introduced (Solomon and Dechter, 1995). Similarly, the use of a computer in the consultation room did not depersonalize patients' relationship with the physician, nor did it enhance satisfaction with the thoroughness of the examination or confidence in the physician's findings (Aydin, et al., 1995).

Patient centeredness

Although the use of electronic medical records often has a positive impact on information exchange, computerization may threaten the emphasis on patient centeredness (Pearce and Trumble, 2006; Shachak et al., 2009). Here, the proficiency of the health care professionals may be important: Patients seen by physicians under training, compared to those seeing more experienced physicians, more often agreed that consultation room computers decreased the amount of interpersonal contact. (Rouf, et al., 2007)

Link between computer usage and patient outcomes

The above characteristics show that there is an effect from stationary computers in primary care on doctor-patient communication. Since doctor-patient communication has an effect on patient outcomes, it is likely that there is an indirect link between the use of computers and patient outcomes (Figure 4).

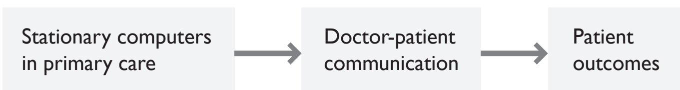


Figure 4. There is an indirect link between the use of stationary computers in primary care and patient health outcomes through doctor-patient communication.

2.6. The impact of mobile computers on doctor-patient communication

To support the information needs of clinicians at the point of care, mobile computers are being introduced in ward round situations as an alternative to the paper chart. In general, little research has been done to investigate the impact of mobile computers on doctor-patient communication. However, the few studies found on the topic suggest that many of the effects related to doctor-patient communication that exist for stationary computers in the consultation also hold for mobile point-of-care systems.

A review of studies comparing the use of paper charts and handheld computers showed that handhelds in general are a faster and preferred alternative to paper-based data collection (Lane et al., 2006). However, paper-based media have much richer interaction capabilities and accessibility compared to electronic media, such as PCs and PDAs (Dahl et al., 2006).

Although the introduction of handheld systems in point-of-care situations can have a good effect on information accessibility (Ilie et al., 2009), some studies have shown that bedside usage of handheld devices can have a negative effect on both the patient and physician (Houston, 2003; McAlearney et al., 2004).

Houston et al. (2003) reported on how ninety-three American patients perceived doctors' use of handheld computers. They found that only 10 % of the patients disliked the idea of handhelds in the consultation room. However, only 9 % of these (8 patients) reported that their doctor actually *had* used a handheld in the consultation room. The study also included young doctors. Twenty-three percent of them reported that they had reservations about using a handheld in front of the patient, but the study did not mention reasons for their opinions.

Based on a series of focus groups, McAlearney et al. (2004) reported on doctors' experience with handhelds in clinical practice. The doctors' main concerns about handhelds were about the device itself (loss, breakage, and reliability), information security, and user dependency. However, the most interesting concern in this context was their fear that clinical practice might change for the worse. Doctors were worried that patients would have negative impressions of them using handhelds or think they were incompetent if they needed to use one. In addition, some were concerned that enthusiastic colleagues would focus too much on the device and forget to care about the patient.

In a series of experiments with bedside computers in a full-scale usability laboratory, health workers and patients were observed while simulating clinical encounters (Alsos and Svanæs, 2006; Dahl and Svanæs, 2008). In these experiments, some of the participating physicians reported that the handheld was a disturbing element in the conversation with the patient (Alsos and Svanæs, 2006). The same observation was made in a series of experiments that compared bedside methods for automatic identification of patients to access medical information (Dahl and Svanæs, 2008). Here, health workers clearly preferred design alternatives that did not require them to shift their attention away from the patient.

The way mobile systems are integrated into the doctor-patient dialogue seems to have an effect on the patient. For example, patients rate interactions with their physicians more positively when physicians explain their PDA use (McCord et al., 2009).

When summarizing current knowledge on best practice doctor-patient communication and the reality with stationary and mobile computers (Table II), it becomes apparent that there is little knowledge on how communication changes when mobile computers are used in the presence of patients. We cannot confidently know whether there is a link between the use of mobile computers in hospitals on patient outcomes (Figure 5).

Figure 5: The link between the use of mobile computers in hospitals with patient health outcomes is not yet established (dotted arrow) as we have limited knowledge about the effects of mobile computer usage on doctor patient communication.

Table II. Characteristics of doctor-patient communication, best practice, and current knowledge on the influences of stationary and mobile computers.

Characteristics of doctor-patient communication	Best practice in patient consultations	Current knowledge about computers in primary care	Current knowledge about mobile computers
Information exchange	Patient allowed to provide information uninterrupted, physician provides enough information	Less medical dialogue, but more information exchange and better explanations	Faster data collection
Shared decision making	Decisions are made by agreement of both physician and patient	Computers can enhance shared decision making	(No data)
Trust	Trust is established between physician and patient	(No data)	(No data)

Technical competence and efficiency	Physician displays efficiency and high technical competence	Good computer skills improve communication with patient	(No data)
Use of language	Physician uses everyday language	(No data)	(No data)
Practice of non-verbal behavior and eye contact	Physician uses non-verbal behavior, such as touch and eye contact	Computer use may reduce non-verbal behavior and eye-contact	(No data)
Physical room layout	Room layout supports communication	Spatial configuration of computer can disturb communication	(No data)
Time spent reviewing patient charts	Physician reduces time reviewing patient charts	Physicians will spend more time on computer and less time on patient	Worries about device focus leading to less patient care
Instrumental and affective utterances	Physician uses both task focused and socio-emotional utterances	(No data)	(No data)

2.7. The concept of awareness and its relevance in point-of-care situations

One way of viewing a ward round, is as collaboration between the doctor and the patient (Buchanan et al., 1998). Add technology, such as a mobile electronic patient record system, and the ward round becomes an instance of *computer supported collaborative work* (CSCW). This makes concepts and ideas from CSCW relevant, such as *awareness*.

Awareness defined

Awareness is a critical and central concept in research on CSCW (Schmidt, 2002). It is an important element of collaboration activities. The concept originally emerged from a number of workplace studies, which revealed that collaborative activities were dependent on people being sensitive to each other's work while performing different activities. In one of the early attempts to define awareness, Dourish and Belotti (1992) explain the term as "an *understanding of the activities of others*, which provides *a context for your own activity* [original emphasis]". Now, a number of diverse sub-definitions and usage of the term are making it hard to navigate in the range of awareness definitions (Schmidt, 2002).

The importance of awareness in the ward round

Since the ward round is face-to-face, normal rules for taking turn holds (Sacks et al., 1974). However, artifacts such as the paper-based patient record also have a role in the conversation (Heath, 1986; Luff and Heath, 1998). Depending on the physician's work habits, he or she needs at some point to take notes, prescribe medication or order lab tests based on the information that the patient provides. When doing this, the physician has their attention directed towards an information device, but still has to be aware of the patient's (and colleagues') actions to maintain the communication flow.

Similarly, the patient has to be aware of the overall care situation, such as the clinician's actions to avoid interrupting or disturbing her. In addition, patients use subtle cues, utterances and body posture to make the physician aware of, and to emphasize their symptoms and problems. Moreover, by being aware of what the physician has understood from the dialogue, the patient can go into detail on certain aspects and dismiss the importance of other aspects.

Understanding how awareness is achieved

How is a person made aware of colleagues' work? Or more specifically, how are clinicians and patients made aware of each other's actions? Below, we will explain some relevant views on awareness:

Configuring awareness: A common conception of awareness is that it is something "hidden", abstract, and implicitly produced in collaborative co-located situations (such as "peripheral awareness" or "mutual awareness"). However, Heath et al. (2002) suggest that awareness is not only about people being sensitive about the actions of others, but that awareness is *configured* by deliberately displaying relevant actions to colleagues to enable them to act a certain way. In other words: colleagues constantly *monitor* each other's actions to understand how this might have consequences for their own work, and while performing their own work, they deliberately *display* their actions so that colleagues can monitor them (Schmidt, 2002; deSouza and Redmiles, 2007).

By-product and add-on awareness: Simone and Bandini (2002) use the classes *by-product* and *add-on awareness* as means of promoting awareness. The first refers to awareness information that is produced as a side effect of the actions that people must do in order to perform collaborative tasks. For example, a doctor reading the patient record will, as a side effect, inform the patient that she is currently unable to see his problem. This will cause the patient to delay his inquiry until the doctor has re-established eye contact (Heath, 1986). Slightly simplified, by-product awareness does not cost anything to produce or consume in a collaborative setting and is implicitly created during work.

Add-on awareness refers to a more explicit way of promoting awareness *on top* of by-product awareness. For example Gutwin et al. (1996) describe how people are thinking their actions out loud to make colleagues aware of their work and behavior. Other examples of add-on awareness are adding notes to forms, intensifying gestures or voice, or moving into unexpected places (Simone and Bandini, 2002). Add-on awareness requires extra effort to produce compared to by-product awareness.

Using artifacts to achieve awareness and coordination: Robertson (2002) describes how artifacts are important means for collaborating actors to achieve awareness and coordination, and further explains how these artifacts need to be publicly available to the actors. Moreover, Robertson reports that the importance of artifacts and actions changes constantly over time, possibly with the actors' changing experience. Other CSCW studies report how artifacts are essential for collaborative work, such as the importance of the subway timetable for traffic controllers at the London Underground (Luff and Heath, 1998), and the flight progress control strips for air traffic controllers (Hughes et al., 1988).

Visibility of input actions: The characteristics of the input actions suggest that interaction can be anticipated when actions are visible (Gutwin and Greenberg 2002). For example, when using interactive multi-user tabletops a user's actions are highly visible and can therefore be anticipated by other users. In contrast, mouse input makes hand movements smaller, and in addition the cursor is small and disconnected from the user (Hornecker et al., 2008). This makes anticipation of the user's actions more challenging.

2.8. Conclusions

Although there is little research on the impact of mobile computers in health care on doctor-patient communication, there is strong reason to believe that many of the issues with stationary computers in primary care also hold for mobile point-of-care systems. The use of mobile systems in health care may not only have consequences for clinicians using them, but it may also have consequences the patient; ranging from minor irritation because the physician is more engaged in the computer than the patient, to serious medical errors that risk the life of the patient. In addition, previous studies have shown that awareness is a vital component for successful collaboration and communication between doctors and their patient. This chapter has provided the motivation for the first research question:

(1) *How do mobile point-of-care systems affect doctor-patient communication in ward round settings?*

Next, I will present knowledge on mobile electronic patient record systems in health care.

3. Mobile Electronic Patient Record Systems in Health Care

In the previous chapter the link between technologies used in point-of-care consultations and patient health outcomes through doctor-patient communication was established. This chapter aims to provide the research context and theoretical background necessary to understand the results and implications of the present work. In particular, it will give an overview of the concepts of *usability*, *users* and *user experience*, and define mobile point-of-care systems and its context of use. Further, the chapter presents important quality criteria for such systems.

3.1. Usability, users and user experience

Users, usability and user experience are three important concepts from the field of Human Computer Interaction (HCI). Below, these concepts are defined and described.

Usability

As pointed out in numerous studies, good usability is one of the cornerstones in a successful introduction and use of both stationary and mobile EPR systems in hospitals (Ash et al., 2003; Sittig and Singh, 2009). But what is usability and how are usable systems designed?

Usability is often an important user requirement or quality criteria for ICT solutions. The international standard ISO 9241-11 (1998) defines usability as:

> "[The] extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use."

Further in the ISO standard, *context of use* is defined:

> "[Context of use is] users, tasks, equipment (hardware software and materials), and physical and social environment in which a product is used."

Therefore one cannot talk about usability as a property of a product, but rather as something relative to the context in which the product is used.

Aspects of usability, such as *effectiveness* and *efficiency*, can be measured with objective and quantitative metrics such as task completion and task completion time. *Satisfaction* is more subjective and requires qualitative metrics.

A number of HCI publications refer to a 1997 draft (e.g. O'Grady et al., 2005) of ISO 9241-11 (1998). This old version of the usability definition contained reference to users of a system, but also to "*other people affected by its use*". However, this reference was for some reason omitted in the final version of the usability definition.

Human centered design process

Despite slow adoption, the software industry is increasingly embracing the *human centered design process* or similar processes, where iterative development is a key concept to ensure usable ICT systems (Seffah and Metzker, 2004). The International standard 9241-210 (2010) (which is a further development of ISO 9241-11) defines the human centered design process as a cyclic process with four steps (Figure 6), which are repeated as many times necessary (or as long as the budget allows) until the system or device has the right quality and meet the requirements set:

1. Understand and specify the context of use
2. Specify user and organizational requirements
3. Produce design solutions
4. Evaluate design against requirements

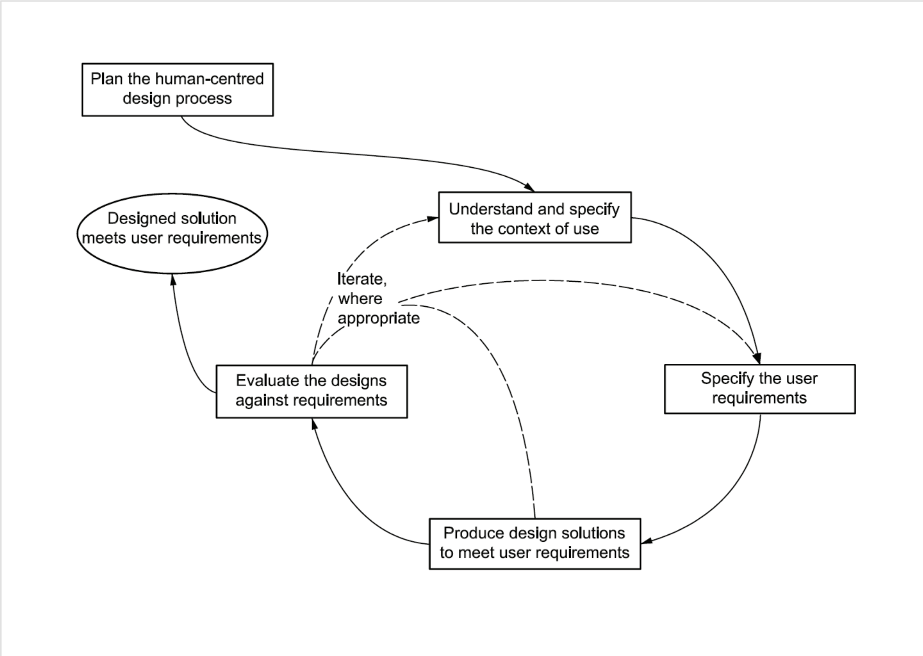


Figure 6. The human centered design process (ISO 9241-210, 2010)

Users

Traditionally, an *end-user* is considered the person who interacts directly with an information system. However, end-users, as defined by Faulkner (2000), can be (1) *direct users*, who use the system themselves, (2) *indirect-users*, who ask other people to use the system on their behalf, (3) *remote users*, who do not use the system, but depend on the output, or (4) *support users*, who ensure that the system works for others, such as primary users.

Other researchers have defined other comparable categories of end-users. For example, Eason (1987) identifies three categories of users; (1) *primary users,* who are frequent hands-on users of the system; (2) *secondary user*s, who are occasional users or use the system through an intermediary, and (3) *tertiary users,* who are affected by the introduction of the system or influence its purchase (Figure 7). The primary user corresponds to Faulkner's direct user, the secondary user corresponds to the indirect user, and the tertiary user corresponds to remote and support users (see Table III).

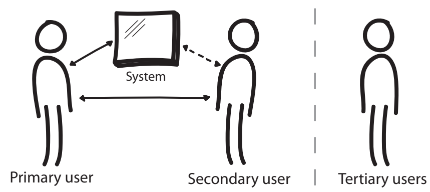


Figure 7. The primary user interacts directly with the system. Secondary users are occasional users or use the system through an intermediary. Tertiary users are affected by the introduction of the system.

Similarly, Ågerfalk (2001), drawing on actability theory, also defined three types of users, (1) *the performer*, who performs a communicative act by using the system, (2) *the interpreter*, who receives and interprets the information from the performer, and (3) *the communicator*, who uses the system on behalf of an organization or third party to communicate offers to a customer. In Ågerfalk's definition (op. cit.), the performer corresponds to Faulkner's direct user, the interpreter corresponds to the remote user, while the communicator relates to the indirect user. Table III presents an attempt to show how the different end-user categories correspond to each other. The correspondence is however somewhat blurry and inexact since the categories are defined differently.

Table III. Different end-user categorizations and how they relate to each other.

Faulkner (2000)	Eason (1987)	Ågerfalk (2001)
Direct user	Primary user	Performer
Indirect-user	Secondary user	Communicator
Remote user	Tertiary user	Interpreter
Support user	(Tertiary user)	N/A

Thorough work is often done in identifying stakeholders in the requirements process, but end-users are mainly considered those who directly interact with the system (Sharp et al., 1999). My own experience as a usability specialist supports this view; designers and developers are to some extent aware of the peripheral end-user groups, i.e. those who do not directly interact with the systems, but few actually design for them. They mainly take the direct/primary user into account when designing system.

In many use situations, especially from client-service relations, primary users of information systems are engaged in face-to-face interaction with customers. They may for example be a client making a deposit in a bank, a globetrotter booking a flight in a travel agency, or a customer buying products in a shop. These types of customers are recognized by the following characteristics:

- They are interacting with the primary user, who interacts with the system.
- They are not (or in little extent) interacting directly with the system themselves.
- They rely on the primary user to obtain information from the system.

- They are influenced by the primary user's experiences with the system (e.g. effectiveness, efficiency, satisfaction, etc.)

To my knowledge, there is hardly any focus on this group of users in the literature. A noteworthy exception is provided by Montague (2009), who claims that patients have a user experience of the technology used by care providers, even if they are passive users of it: During childbirth, the health care providers use technology to monitor the health condition of the unborn child. By interviewing mothers about the technology used on them, Montague found that when technology worked well, it created positive experiences and increased the patients' connection with their babies. When technology did not work well or when care providers could not get technologies to work properly negative experiences occurred.

User experience

User experience, as defined in ISO 9241-210 (2010), is "*a person's perceptions and responses that result from the use or anticipated use of a product, system or service*". Others have proposed comparable definitions, such as Law et al. (2009), who propose that "user experience focuses on interaction between a person and something that has a user interface".

Although usability and user experience are conceptually linked, they highlight different elements of the interaction between a human and a computer. While user experience is subjective and focuses on the use, usability is more objective and quantifiable. The perceptions and responses that affect user experience include all the users' emotions, preferences, beliefs, perceptions, physical and psychological responses, behavior and accomplishments that occur before, during and after use. As for usability, user experience is relative to the context of use (Law et al., 2009).

Co-experience

The definition of user experience implicitly excludes face-to-face interaction between people, unless a user interface is involved in the interaction (Law et al., 2009). For face-to-face interactions, *Co-Experience* provides a better explanation; it is the user experience created in social interaction with the presence of a system or product (Battarbee, 2003). User experience and co-experience relates as follows: While user experience mainly concerns the primary user, co-experience relates to both the primary and secondary user (Figure 8).

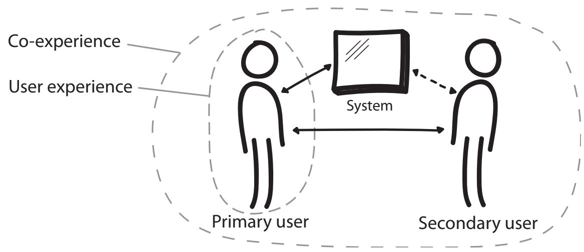


Figure 8. User experience relates to the primary user, while Co-experience relates to both the primary and secondary users. The solid arrows indicate direct interaction, while the broken arrow indicates indirect interaction.

3.2. Characteristics of mobile EPR systems and their context of use

As described in the previous chapter, health care professionals need information about the patient during consultations. The patient contributes with some of the information, while much is provided through paper-based or electronic patient records. This section presents the characteristics and demands of different paper-based and electronic support tools for the ward round.

Paper-based medical records

The paper-based medical record is the analogue counterpart of mobile EPR system. In paper-based hospitals, medical records consist of information about patients' condition, the treatment they receive, and effects of the treatment. The paper record is the externalized memory of the hospital; it helps clinicians in patient consultations, and also acts as the hospital's legal archive (Coiera, 2003).

The entire medical record of a patient is often too large and extensive to bring into point-of-care situations. Therefore, clinicians in Norwegian hospitals often bring a summary or subset of the entire patient record as on-site documentation during patient visits (Melby, 2007). "The Chart" (as it is widely named by its users) is a collection of the most important medical documents about the patient, gathered in a binder (Figure 9, *left*). The main document is an A4 size form containing the most important information about the patient, such as vital signs, prescribed medication etc. (Figure 9, *right*). In addition, the binder contains other documents such as recent test results or reports.

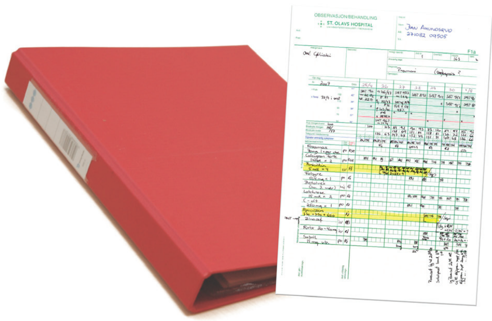
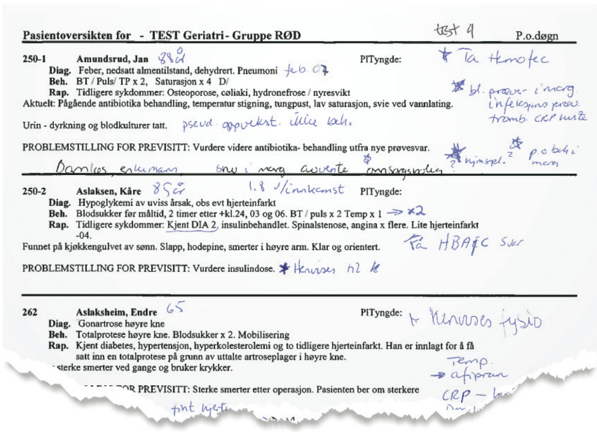


Figure 9. The paper record (*left*) and the paper chart (*right*)

In addition to the paper chart, the health care personnel rely on a patient overview displaying a short summary of all the patients in a particular hospital ward (Figure 10). This information source is a single paper sheet folded and carried in the pocket when not in use. For many health care professionals, especially nurses, this paper sheet is considered the most important tool they have. It is used as a memory aid and to take notes on.


Pasientoversikten for - TEST Geriatri - Gruppe RØD P.o.døgn

250-1 **Amundsrud, Jan** PlTyngde:
Diag. Feber, nedsatt almentilstand, dehydrert. Pneumoni
Beh. BT / Puls/ TP x 2, Saturasjon x 4 D/
Rap. Tidligere sykdommer: Osteoporose, cøliaki, hydronefrose / nyresvikt
Aktuelt: Pågående antibiotika behandling, temperatur stigning, tungpust, lav saturasjon, svie ved vannlating.
Urin - dyrkning og blodkulturer tatt.
PROBLEMSTILLING FOR PREVISITT: Vurdere videre antibiotika- behandling utfra nye prøvesvar.

250-2 **Aslaksen, Kåre** PlTyngde:
Diag. Hypoglykemi av uviss årsak, obs evt hjerteinfarkt
Beh. Blodsukker før måltid, 2 timer etter +kl.24, 03 og 06. BT / puls x 2 Temp x 1
Rap. Tidligere sykdommer: Kjent DIA 2, insulinbehandlet. Spinalstenose, angina x flere. Lite hjerteinfarkt -04.
Funnet på kjøkkengulvet av sønn. Slapp, hodepine, smerter i høyre arm. Klar og orientert.
PROBLEMSTILLING FOR PREVISITT: Vurdere insulindose.

262 **Aslaksheim, Endre** PlTyngde:
Diag. Gonartrose høyre kne
Beh. Totalprotese høyre kne. Blodsukker x 2. Mobilisering
Rap. Kjent diabetes, hypertensjon, hyperkolesterolemi og to tidligere hjerteinfarkt. Han er innlagt for å få satt inn en totalprotese på grunn av uttalte artroseplager i høyre kne.
sterke smerter ved gange og bruker krykker.
R PREVISITT: Sterke smerter etter operasjon. Pasienten ber om sterkere

Figure 10. The patient overview is an important information source and note-taking device for the nurses (the names are not authentic).

In Norway, most hospitals have introduced electronic medical records to replace the paper-based records (Lærum et al., 2001). However, in point-of-care situations clinicians still rely on the paper chart with paper printouts of the EPR in lack of good mobile electronic alternatives.

Mobile technology

There is at present no consensus on a definition of mobile technology. Weilenmann (2003 p. 24) defines mobile technology as "a technology, which is designed to be mobile". In this thesis the more precise definition below is used:

> [Mobile technology] is technology that provides digital information and communication services to users on the move, either through devices that are portable per se, or through fixed devices that are easily ready at hand at the users' current physical position (*Paper 2, Methodological and practical challenges*).

The definition includes computing devices such as mobile phones, PDAs, Tablets, and Laptops on wheels (Figure 11). In addition it opens the way for ubiquitous and pervasive technologies, multi-user, and multi-device systems such as patient terminals and collaboration screens. It excludes the desktop computer, defined as a one-user-at-a-time stationary/desktop computer with display, keyboard and mouse.

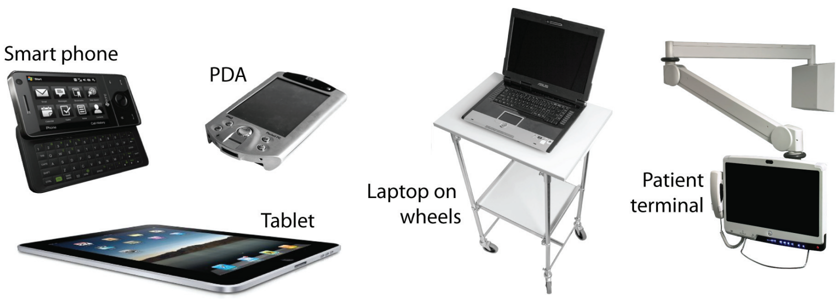


Figure 11. Examples of mobile technology used in hospitals

Mobile medical work in hospitals

While most electronic medical record systems currently only run on stationary computers, empirical studies of clinical work in hospitals show that health workers are constantly on the move in a highly information and communication intensive and event-driven working environment (Bardram and Bossen, 2003; Coiera and Tombs, 1998). EPR content is currently to a large extent produced and utilized in point-of-care settings away from the computers through the use of paper printouts, handwritten notes, and voice memos; while actual interaction with the EPR is done while sitting down at a stationary computer. This creates an obvious potential for mobile computing in healthcare.

Mobile work needs mobile support. A number of studies of existing systems have documented the benefits of mobile computing in health care (Kjeldskov and Skov, 2004; Fisher et al., 2003; Reuss et al., 2004). To best support health workers in their everyday work, the hospital's EPR system should allow for interaction with the patient's medical record at the point of care. However, health workers often change between performing office and mobile work (Figure 12). Mobile support does not necessary mean mobile technology, but technology that is available during mobile work. Stationary patient terminals or wall mounted displays available in hallways or patient rooms can also be seen as mobile support.

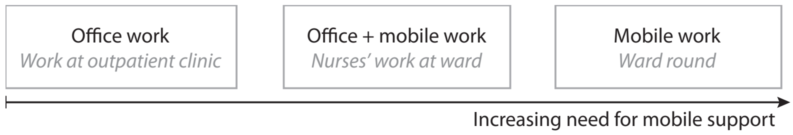


Figure 12. Health workers often change between performing office and mobile work. Different work modes require different mobile support tools.

Usability of systems in mobile work

From a usability perspective, the main difference between desktop-based and mobile computing is related to the use situation. The typical use situation for desktop-based applications is a single user sitting on a chair in front of a table looking at a screen with his or her hands on the keyboard and the mouse. In contrast, mobile technology is to a much larger degree embedded into the user's physical and social life. Dourish (2001) uses the concept of *embodied interaction* when referring to this phenomenon. Embodied interaction, as argued by Dourish, is characterized by presence and participation in the world. As such, interaction with mobile technology is not a foreground activity to the same extent as interaction with desktop-based systems, but switches between being in the foreground of the user's attention and residing silently in the background.

The key to acceptance of electronic patient record systems is that they are easy to use and support doctors, nurses, and other clinicians in the care and treatment of their patients (Bleich and Slack, 2010). However, current health care systems in hospitals often have low levels of usability, and the systems are often time consuming and difficult to use (Beuscart-Zéphir et al., 2007). For example, in a survey done by the Office of the Auditor General of Norway (2008) concerning 336 physicians' use of electronic health records, nearly half of the physicians (46%) in Norwegian hospitals found their EPR systems hard to use. Only one out of five found them easy to use (20%), while one third (34%) found them acceptable.

Healthcare has been slow to incorporate human factor considerations into health care systems (Car et al., 2008), and the EPR industry struggles with low competence in usability and human factors. As an illustration of this, one of the largest EPR vendors in Norway, with over 100 employees, still relies on programmers without usability specialist or design training to design their products (personal communication with CEO, 23 September 2010).

As patient record entries, x-ray images and lab tests are being digitalized the applicability of the patient record is changing. The clinicians are increasingly "meeting" a digital version of the patient through the EPR system instead of meeting the patient in persona. Since they order treatments, request lab tests, or prescribe drugs through the EPR system, the usage is increasingly affecting the patient directly. Deficient EPR systems (e.g. those with poor usability) may therefore put the safety of patients in danger (Svanæs and Faxvaag, 2010).

Poor usability may lead to stress and increase the probability of medical errors, such as wrong ordering of medication, incomplete medical records and lost information (Ash, Berg et al., 2004). The consequences of medication errors for the patient can range from mild discomfort to serious injury or death. In Norway, with a population less than five million, it has been estimated by the Norwegian Board of Health Supervision that between 500 and 1000 people die every year because of medication errors (Hansen and Blomquist, 2002). Another study showed that every fifth death in Norwegian hospitals was caused by medication errors (Hanssen and Bruun, 2002). This shows that usability is not only a cosmetic problem for the user, but can have serious unintended consequences for patients.

Attention demands of systems in mobile work

Attention is often described as a limited human resource. We cannot attend to everything at the same time and must direct our cognitive resources towards parts of our sensory inputs so that the stimulus of most interest can be processed (Duchowski, 2003). In addition, there is an overhead cost associated with the shift of attention between different tasks; focus shifts consume cognitive resources (Lund, 2001).

Unfortunately, many of the existing interfaces on both desktop and mobile computers require relatively fine motoric control and coordination, and demand frequent context shifts between the system and the surrounding world. The high cognitive effort used to operate them reduces the attention available for other tasks. This is a particular problem in mobile work because there is a constant competition between the environment and the system for the attention of the user (Jameson, 2002). For example, in a clinical setting the mobile device may require so much attention that it reduces the quality of the health worker's primary task, which is looking after the patient. This was found by Dahl and Svanæs (2008) who observed how usability breakdowns caused attention to be drawn away from the patient and towards the mobile user interface. Moreover, Alsos (2005) tested several prototypes of a mobile x-ray image viewer and observed how the mobile device was "stealing" the physician's attention from their patients.

When developing mobile systems for cognitively disabled, blind, deaf and elderly users, designers usually take the attentional limitations of the target group into account. Examples are designs with larger buttons, fewer colors and redundant output formats such as visual, tactile and audio feedback. However, it is claimed that designing for disabled can be advantageous even for persons with normal abilities, particularly when the system are used in stressed situations with extensive stimuli or shared attention (Fuglerud, 2007). Point-of-care situations are brilliant examples of such contexts-of-use, where clinicians have to share their attention between several tasks, patients and colleagues, often under severe time pressure.

Another way of addressing the challenges with attention-demanding mobile systems is to design the system so that it requires a minimum of the user's attention (Pascoe et al., 2000). Large buttons, predefined text input, and simplified workflows that can be learned and memorized allow the user to direct most of their attention into the world, rather than on the mobile system.

The examples above illustrates that when mobile technology usage is embodied in the world, the technology should be designed to require a minimum of attention, or to make it easy to switch between mobile usage as a foreground and background activity.

Properties and affordances of mobile systems

Gibson (1977) used the term *affordance* to describe what an environment and its objects offer to a specific person. The same environment/object provides different affordances for different persons according to characteristics such as age, skills, and abilities. For a patient admitted to a hospital, a patient bed affords lying down, while for a physician it affords a place to put the paper chart when both hands need to be free. A night table affords a place for the nurse to place patient's medication, while for the patient it affords a place to keep magazines and personal belongings. Norman (1999) points out that an affordance is a *relationship* between an object, a user, and the context it is used. Thus is it only meaningful to talk about *perceived affordance*: An object has potentially unlimited affordances, but only a set of them are perceived by the user and are relevant in a particular context.

A number of studies have analyzed the affordances of paper-based and digital information devices (Bang and Timpka, 2003; Bardram and Bossen, 2003; Dahl et al., 2006; Harper et al., 1997; Luff and Heath, 1998). When moving from paper-based to digital media in hospitals, some affordances such as high ecological flexibility and non-disruptiveness, which are essential for collaboration, are lost. On the other hand, digital media can open up new affordances, such as remote concurrent interaction or access to updated medical information (Dahl et al., 2006).

3.3. Mobile point-of-care systems in use

EPR systems have a very high dispersion rate in the Norwegian health sector, which is nearly 100 percent in both the primary and secondary care (Norwegian Research Centre for Electronic Patient Records and Norwegian Directorate of Health, 2008). There have been several initiatives going on in Norway to produce mobile EPR systems for use in hospitals, but none are in production yet.

In 2004 a large regional hospital in Norway started developing a mobile point-of-care system in cooperation with an EPR vendor. In 2010, after several delays, the finished system was piloted at one hospital department. After only two months the pilot was stopped because of frustrated users who experienced usability problems, low efficiency and slow response times (Helgesen, 2011).

Similarly, another EPR vendor started their mobile EPR pilot project as early as 2002 (Kristensen and Lyche, 2003). At the present time, the vendor still has no mobile EPR system in their product portfolio.

3.4. Quality criteria of mobile health information systems

When evaluating the quality of diamonds, there are four important quality criteria, (known as "the four C's"); *clarity*, *carat*, *color* and *cut*. When magazines evaluate consumer products, for example digital cameras or mobile phones, criteria such as price, usability, functionality and image/display quality are often used. Similarly, for mobile health information systems there could be formulated a number of quality criteria, but currently, as far as I have found, no such complete list exist.

Important quality criteria

Reviewing literature has revealed a number of such quality criteria acquired from empirical studies, as shown in Table IV. To make the list of quality criteria clearer and more comprehensible, the criteria are grouped in categories. The criteria have been derived from the results, main topics discussed, or evaluation criteria used in the different studies. However, the list of criteria is not complete and it remains to find out what is really important for health information systems.

Table IV. Quality criterion for mobile health information systems

Quality criterion	Description	Example studies
Usability		
Ease of use	System is easy to use	Bleich and Slack (2010)
Learnability	System is fast and easy to learn	Boone (2010)
Attention-easy	Require little attention	Alsos and Svanæs (2006)
Efficiency	Fast to use	Haller et al. (2009), Wu et al. (2008)
Security/privacy		
Privacy	System protect patient information	Watson (2006), Strayer et al. (2010), Kusche (2009)
Access control	Fast and simple, yet secure log in	Watson (2006), Bardram (2005), Dillema and Lupetti (2007)
Organizational issues (hospital management perspective)		
Return on investment	Saving costs in long run	Wu et al. (2008), Wang et al. (2003)
Business management	Integration with billing and administration systems	Fischer et al. (2003), Lu et al. (2005)
Price	Reasonable investment cost	Carlson et al. (2010)
Time saving	Saves clinicians' time	McCord (2003)
User satisfaction	Increases users' career satisfaction	Elder et al. (2010)
Training issues	Reduced training hours	Boone (2010)
Productivity	System enhance productivity	Lu et al. (2005)
Functionality		
Activity-based support	Use is based around activities, which can be suspended, handed over, etc.	Bardram (2009)
Functionality	Offering useful, effective functionality for high-yield tasks	Ying (2003)
Customization	Functions and programs can be added	Lu et al. (2005)
Context sensitivity	Ability automatically discover and react to changes in environment	Skov and Høegh, (2006)
Information/integration		
Information accessibility	Access to a broad range of clinical data and reference tools	Ilie et al. (2009), Garrett and Klein (2008)
Effective data access	Fast to access information	Reuss et al. (2004)
Real-time access	Accessed information is continuously updated	Lu et al. (2005)
Clinical decision support	Provides support for clinical decisions	Garrett and Klein (2008)

Data collection	Fast and effortless data entry	Lane et al. (2006), Reuss et al. (2004), Seneviratne and Plimmer (2010)
Communication	Communication capabilities with colleagues	Dahl et al. (2006)
Information sharing	Technology must support sharing information with colleagues	Tang and Carpendale (2008)
Ubiquitous information access	Information can be accessed from anywhere.	Varshney (2007)
Device properties		
Weight	Lightweight	McAlearney et al. (2004)
Processing power	Fast	Ying (2003)
Screen size and resolution	Large screen and resolution	Ying (2003), Wu et al. (2008)
Battery capacity	High battery capacity needed	McAlearney et al. (2004)
Connectivity	Wireless data access	
Integration	Device is integrated with other systems and reference tools	Wu et al. (2008)
Input methods	Effective interaction techniques	Dahl and Svanæs (2008), Wager et al. (2010)
Life cycle	Long life-time before being technologically outdated	Garrett and Klein (2008)
Hygiene	The device should be cleanable	Neely et al. (2005)
Reliability	The device does not break or malfunction	McAlearney et al. (2004)
Mobility/portability	Degree of mobility offered by device	Andersen et al. (2009), Garrett and Klein (2008)
Medical outcome		
Quality of care	Device usage enhance quality of care	Lu et al. (2005)
Error prevention	User errors are prevented. User are alerted when errors occur	Boone (2010), Caroll et al. (2002), Grasso et al. (2002)
Patient safety	Increases patient safety	Lu et al. (2005)
Patient care		
Patient attitudes	Patients are positive towards system	Houston et al. (2003), Strayer et al. (2010)
Patient focus	Enable clinicians to focus on patients (rather than technology)	Nøhr et al. (2001)

Analyzing the quality criteria

The quality criteria listed above have relevance for a number of actors or stakeholders in the hospital. Figure 13 shows how the categories relate to some of the different actors.

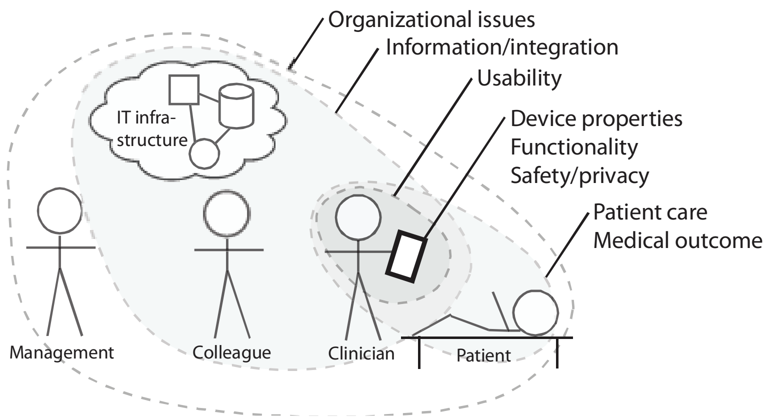


Figure 13. Categorization of quality criteria and how they relate to different actors in the hospital.

When evaluating the list of quality criteria in Table IV together with the overall picture in Figure 13, there is relatively high focus on the technical properties of the device (e.g. battery lifetime, connectivity and weight), the functionality and security/privacy of the system, as well as its usability. In contrast, there is little focus on sociotechnical challenges. In addition, information integration and organizational issues are emphasized. Quality criteria that are important for the patients, such as patient care and medical outcome, are also covered, but a majority of the studies focus on other quality criteria, which are relevant from the perspective of the clinicians or the hospital management.

3.5. Conclusions

Existing mobile point-of-care systems in hospitals appear to be designed from the perspective of clinicians and the hospital management. They comply with "hard" and countable criteria, such as battery lifetime, integration, return on investment, security, and functionality. Sociotechnical criteria, such as the ability to enable clinicians to focus on the dialogue with the patient rather than the technology, are hardly covered. This can have negative effects on doctor-patient communication, which may cause undesirable effects on patient health outcome. This provides the motivation for the second research challenge:

(2) How should one design mobile point-of-care systems that support the doctor-patient dialogue?

Next, I will present current knowledge on lab-based usability evaluations, an important method for evaluating the usability of mobile systems.

4. Evaluating Health Care Systems

The previous chapter pointed to a number of challenges regarding the usability of mobile systems in health care. *Usability evaluation* is one of the best and most powerful methods for assessing usability and the general quality of information systems. It is the main research method used in this thesis, and is included as one of the research aims. Therefore this chapter is devoted to describe state-of-the-art and best practice regarding usability evaluations, in particular evaluations of mobile technology in health care.

In this chapter I first introduce usability evaluation methods in the lab and the field. Second, I present some challenges with usability evaluations of mobile technology in hospitals and explain how a compromising approach between the lab and the field can be a good solution. Further, I draw on concepts from training simulations, which can explain and improve usability evaluations of mobile hospital systems.

4.1. Health technology assessments

The goal of *health care technology* is to improve health or to save costs without compromising health (Banta, 2003). This technology can be represented by a number of different things; drugs, devices, medical and surgical procedures, as well as the organizational and supportive health care systems. For example, a cardiac monitor is a health care technology. An oxymeter for measuring the patient's oxygen levels is another.

Evidence based medicine (EBM) has linked evidence to health care practice, for instance through randomized controlled clinical trials (Sackett et al., 1996). In the same way has *health technology assessment* (HTA) proven the value, safety and efficacy, as well as the ethical and legal implications of health care technology (Perry, 1999). For example, before being approved for usage in hospitals, a cardiac monitor must undergo careful assessment to make sure that it does not compromise the patient's health in any way (Norwegian Ministry of Health and Care Services and Norwegian Ministry of Justice and the Police, 2005). Similar assessments, but even more rigorous, are conducted when new drugs are evaluated.

These assessments are divided in four phases (Norwegian Medicines Agency, 2011), which can take several decades and cost up to 2 billion dollars per drug (Adams and Brantner, 2006):

- Phase 1, where human pharmacology is evaluated on 50-150 healthy individuals
- Phase 2, where the therapeutic effects are explored on 100-200 patients.
- Phase 3, where the therapeutic effects are confirmed by studying effects on 500-5000 patients.
- Phase 4, where the long-term effects of therapeutic use is evaluated by studying the entire population using the specific drug.

Mobile EPR systems for bedside usage, as described in Chapter 3, are also health care technology that should be assessed, but the assessments are nowhere near the assessment of drugs. In Norway such systems are carefully assessed with respect to legal implications (e.g. The Ministry of Justice and the Police, 2000). However, there is no legislation covering other facets that have implications on health care, such as patient safety, usability and effectiveness. For health informatics, however, guidelines have been developed for the reporting of assessment results (Talmon et al., 2009) and there are ongoing initiatives in the EU to establish regulations for this purpose[3].

There are many different methods for health technology assessments, which make it possible to accept or reject new technology (Committee for Evaluating Medical Technologies in Clinical Use, 1985). Randomized clinical trials (RCT) are considered the strongest method, with random and blind allocation of test subjects to either an intervention or control group. However, the cost and time associated with RTCs (Adams and Brantner, 2006) make it impossible to apply for every version of a health technology. This is particularly the case for health information systems, which are frequently updated through bug fixes and new version releases.

Another method for assessing health technology is by conducting a *usability evaluation*. For mobile health care systems, it can be used to evaluate most of the quality criteria presented in Table IV in the previous chapter (except some of the organizational quality criteria). In the next section, the state-of-the-art on usability evaluations is presented.

4.2. Usability evaluations

Usability evaluations (also known as *usability tests*) are commonly used to ensure the usability of systems, websites, and consumer products, and are acknowledged as the most important method to identify usability problems in an ICT system and to inform about the

[3] EUNETHTA is a european organization working for HTA in health care (eunethta.eu)

system design (Rubin et al., 2008; Toftøy-Andersen and Wold, 2011). Since the ideas behind usability testing of information systems was developed at Xerox Parc in the late 70s (Bewley et al., 1983), the method has matured to become an established practice in the software industry, with an ISO-defined common industry format for reporting test results (ISO 25062, 2006).

In a typical usability evaluation, a moderator asks a representative user to solve typical tasks on the desktop-based, single-user system being evaluated (Figure 14). By analyzing observations and comments from several users, usability problems can be identified, and in later iterations (cf. Section 3.1) removed from the system (Rubin et al., 2008; Toftøy-Andersen and Wold, 2011). Although not very common, usability evaluations are sometimes conducted with pairs of participants, who solve tasks together while discussing the solution being evaluated (Wildman, 1995).

Figure 14. In a usability evaluation a moderator (*left*) asks a representative user (*right*) to solve typical tasks on the system being evaluated.

The number of test users recommended is debated, but in general it is suggested to evaluate with few participants (often between 3 and 8) followed by a redesign and another evaluation, rather than one large evaluation with many test participants (Nielsen, 1993).

The usual way of recording data from usability evaluations is to capture the screen content together with a video image and voice recordings of the test participants. Often, the user is asked to think aloud while using the system to get insight into the user's mental model of it (van den Haak et al., 2003). *Think-aloud* is one of the most important techniques for capturing user reflection during usability evaluations.

Another important part of usability evaluations is the *post-test interview* conducted with test participants directly after the evaluation. Here, the evaluators can (1) get more insight into the participants' rationale for performing specific actions, (2) collect their subjective opinions and preferences, and (3) listen to new design suggestions by the participants (Rubin et al., 2008; Toftøy-Andersen and Wold, 2011).

There also exists software that records mouse clicks and keyboard typing, and allows the analyst to tag events in the subsequent data analysis[4].

Usability evaluations come in two main categories; *formative evaluations*, where the main purpose is to inform/improve the system design and provide input for redesigns, and *summative evaluations*, which is a final check whether the system has an acceptable level of usability (Redish et al., 2002). A health technology assessment (cf. Section 4.1) can be seen as a summative evaluation.

Related to the human centered design process and usability as described in Chapter 3, the consequences for usability evaluations is that software needs to be evaluated with *representative users*, *real tasks* and in a *realistic environment*. For example, when evaluating the usability of an EPR system for doctors in primary care, real doctors must be used, the tasks need to be typical for primary care work, and the evaluation should take place in an environment similar to a typical primary care office. Such evaluations usually take place in designated usability labs configured as a typical office setting. The labs are provided with possibilities for detailed audio and video recordings (Rubin and Chisnell, 2008). Sometimes are eye-tracking systems used, which allow test moderators to see and record where users look (Duchowski, 2007).

Promoting and capturing user reflections

In addition to reveal where users experience problems while using a system, one of the main objectives of usability evaluations of information systems is to get participants to reflect over their usage. This is particularly the case for formative and early concept evaluations, where the aim is to collect data that can help improve further system design. The methods are think-aloud during the evaluation (Scholtz and Consolvo, 2004; Wildman, 1995), and questionnaires (Dubois et al., 2007) or interviews (Nacenta et al., 2005) after the evaluation.

In comparative usability evaluations test subject try out multiple alternative solutions. Sometimes it can be challenging to collect user reflections using these techniques. Some key challenges of these techniques summarized below:

- Think-aloud puts a high cognitive load on the user (Wildman 1995). It works poorly when tasks or scenarios require participants to interact or communicate with other actors that play a role in the scenario. This is because their attention is directed towards them, not the moderator (Alsos, 2005).

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[4] Examples of such systems are *Morae* by Techsmith (www.techsmith.com) and *The Observer* by Noldus (www.noldus.com).

- Interviews (and questionnaires) do not support the users' memory. Because of users' limited short time memory and the need for test subjects to remember and distinguish between different design alternatives, the techniques are cognitively demanding, especially when the number of tested solutions is high.
- It can be demanding for test moderators to connect users' feedback to the right solution alternative, particularly if the differences are minor and subtle.
- Questionnaires or strictly structured interviews are predetermined and have poor support for follow-up questions from an interviewer (Robson, 2002).
- The usability evaluation and the interview use different cognitive modalities. While test subjects experience visual stimuli when using the design alternatives, interviews traditionally engage the auditory modality.

The food industry has found an interesting solution to these challenges. In comparative studies of taste with children, researchers use picture cards representing food (Guinard, 2000). Similar visual techniques are also seen in other research studies where children are interviewed (Boyden and Ennew, 1997). In HCI-research, however, I have not found any studies explicitly describing such method.

Prototype fidelity

In the field of Human Computer Interaction (HCI), the concept of fidelity has been used to which extent a prototype system is perceived as authentic and realistic by end users (Virzi, 1989). The fidelity concept has been considered a one-dimensional feature ranging from low to high (Figure 15). Unfinished systems are categorized as *Low*, *Medium* or *High fidelity prototypes* according to their state in the development process (Buxton, 2007).

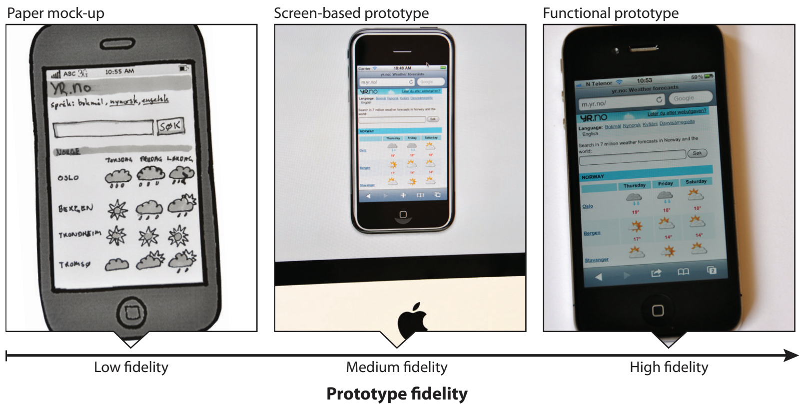

Figure 15. Prototype fidelity is a one-dimensional feature, ranging from low to high. Low-fidelity prototypes are user early in the system development process, and are gradually refined through iterations.

Usability evaluations do not need to be performed on finished systems only. In fact, usability evaluations can be done on rough, unfinished systems without all the functionality implemented, and even on simple paper mock-ups and sketches in early stages of the system development (Figure 15). The benefits are that one can discover usability problems before much investment is put into the system development, and when design changes still are inexpensive to make.

4.3. Evaluating usability of mobile systems

Until fairly recently, most software products being usability tested were desktop based, for single users running on a desktop computer with input through a keyboard and a mouse. This situation has changed as more software is being produced for mobile devices such as mobile phones and PDAs. Moving the user interfaces of EPR systems on to mobile devices creates new challenges for system design and usability evaluation, such as whether evaluate in a lab setting or field setting (Kjeldskov and Stage, 2004), or how to record the evaluation (Oulasvirta, 2009).

Lab or field evaluations

In recent years there has been an ongoing debate within mobile HCI and pervasive computing research concerning best practice for usability evaluations, especially of mobile information systems. In particular, the question of which research settings are optimal for such evaluations has received increased attention (Kjeldskov and Skov, 2007; Kjeldskov et al., 2004; Nielsen et al., 2006). The main conclusions are that lab-based evaluations give the researcher more control over the research setting but with reduced realism, and that field evaluations are realistic but give the researcher less control over the setting and known and unknown variables (Figure 16).

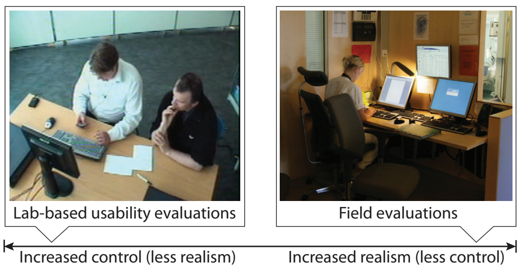

Figure 16. Lab-based usability evaluations give the researcher more control over the research setting, while field evaluations are more realistic (i.e. ecologically valid).

Evaluating mobile point-of-care systems

Recent studies suggest that in order to assess the usability of applications and systems supporting mobile users, it is particularly important that the design solutions are evaluated in realistic use situations (Kellar, et al., 2005; Tamminen, et al., 2004; Kjeldskov and Skov, 2007).

In the hospital setting the traditional usability lab is no longer suitable for evaluating usability of the new generation of hospital software. As mobile systems are replacing desktop-based systems and systems are being collaborative, the lab is unable to recreate the complex and changing hospital context. One obvious solution is to evaluate the software in the field, where the context-of-use is perfectly realistic and where the ecological validity is high. However, the challenges presented below make a trade-of between the lab and the field more appealing:

- Getting access to, and perform usability evaluations in real clinical situations is hard and can interfere with ongoing work.
- Conducting field studies in health care are often associated with high time cost, as well of the cost of interrupting clinical work.
- Patient information confidentiality can be compromised.
- It is often difficult to get ethical approval to record video and audio, which is important data for a usability specialist in identifying usability problems and for researchers in studying the fine details of interactions between people and computers.
- The prototypes often need to be fully functional and stable when being evaluated in the field, whereas in the lab one can use prototypes of lower fidelity. This saves time and development costs.

The solution has in the recent years been to use *simulation-based usability assessments*, which is "a usability test in which the design concept being evaluated is employed by end users enacting constructed work scenarios in natural-like physical environments" (see *Paper 3 – Fidelity considerations*). It is a compromise between field studies and lab experiments where one attempts to recreate realism while retaining control (Figure 17). The approach is also called *in sitro* evaluations (Kjeldslov and Skov, 2007) or *in replica* evaluations (Favela et al., 2010) evaluations. The approach allows researchers to (1) get immediate access to relevant situations, (2) make it easier to collect feedback from participants during and after the study, (3) make recordings of detailed audio and video simpler, and (4) make ethical approval more probable. Most important, the approach (5) does not interfere with patient security and safety.

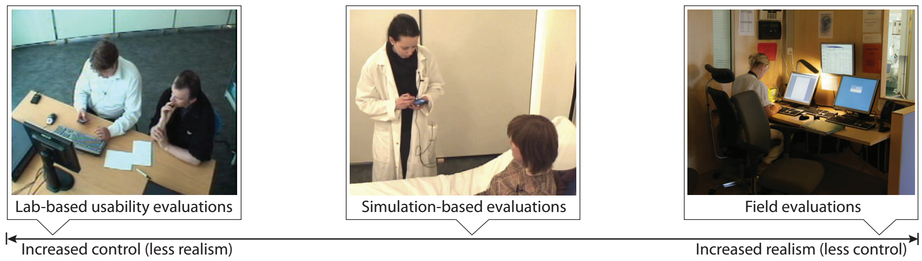

Figure 17. Simulation-based usability evaluation is a compromising approach where one attempts to recreate realism from the field while retaining control over the research setting in a laboratory.

The hospital as a work environment makes usability evaluations even harder, as compared to for example everyday use of mobile phones. Mobile ICT in healthcare is often integrated with a number of other ICT systems, serves a number of different user groups, and must allow for use in a number of different physical environments.

One study (Kjeldskov and Skov, 2004), found that simulating a clinical use context (i.e., physical environment and work tasks) in a laboratory to a large extent enabled identification of the same usability problems that were revealed through comparative field evaluations. Another study (Bardram and Hansen, 2004) indicated that evaluating technical designs in realistic scenarios helps participants to reflect on envisioned solutions as if they had been tested in their real work environment.

Recording techniques

When recording usability evaluations of mobile technology, recording techniques should support mobility, capture embodied interaction, be unobtrusive, support multiple data sources, be redundant and make the test moderator aware about the quality of data (Oulasvirta and Nyyssönen, 2009). These recording techniques are often *moderator controlled, user-worn* or *device-worn*.

- The moderator-controlled technique typically means that a moderator follows the user with a handheld camera (Figure 18 b). This technique does not allow studies without the moderator present.
- With the user-worn technique one or more cameras are attached to the user (Figure 18 a and b). In addition to the cameras, this technique often requires the users to carry backpacks, batteries and recording devices that can interfere with their real world tasks.
- The device-worn sources involve a camera attached to the mobile device (Figure 18 c). This technique prevents the user to use the device naturally and makes it hard to stow away when not using it.

Overall, these recording techniques conflicts with the need for ecological validity.

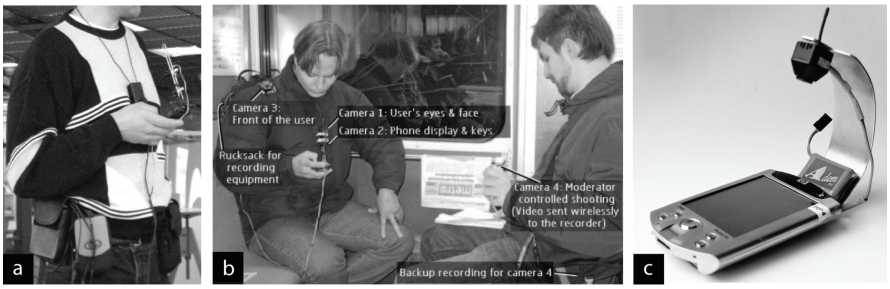

Figure 18. Current usability evaluation studies use obtrusive recording techniques. They require the user to carry backpacks, wires and recording equipment (a and b), or require an observer to follow and record the user (b) (Photo a and b: Oulasvirta and Nyyssönen, 2009). Device-worn solutions prevent the user to stow the device away when not using it (c) (Photo c: Ram Yoga).

4.4. Training simulations

Training simulations are commonly used in high-risk industries such as aviation, naval shipping and health care to give participants relevant skill training. This is typically done with the use of simulators, which attempt to represent the real work situation, while at the same time being able to omit some aspects of the real situation to make it manageable for both the trainer and the trainee. In health care, for example, training simulations with medical students and patient actors are often used to train the students in the art of diagnosing and communicating before being exposed to real patients.

Comparison of training simulations and usability evaluations

There are a number of similarities between training simulations and realistic usability evaluation. Both attempt to reproduce elements of a real work situation in a controlled manner. In addition, both involve real users attempting to solve realistic tasks. There are also a number of differences, which are summarized in Table V. For a comprehensive argument, see *Paper 3* in this thesis.

Table V. The main differences between training simulations and usability evaluations.

	Training simulations	**Usability Evaluations**
Purpose	Enhance human skill performance in a specific context	Evaluation of product performance relative to a particular context
Knowledge recipient	Trainee	Evaluator
Role of technology	Part of simulator	Product to be evaluated
Role of participant	As trainee	As representative user
Output	Skill	Product acceptance and usability

Simulation fidelity components

As with usability evaluations, there is also an ongoing debate in research on training simulations about the degree of realism, or fidelity, that needs to be mirrored in simulations in order to maximize transfer of training.

Simulation fidelity defines the reality of the training simulation (Alessi, 1988; Gross et al., 1999), and it can be divided into a *physical fidelity* component and a cognitive or *psychological fidelity* component (Figure 19). The physical component can be further divided into *equipment fidelity*, which is the appearance of tools, devices and systems, and *environment fidelity*, which is the visual, auditory and motion stimulus. Further the psychological component can be divided into *task fidelity*, which describes the degree to which real-world tasks are replicated in the simulation, and *functional fidelity*, which describes whether the simulation appears like "the real thing". The full details can be found in Section 3 of *Paper 3*.

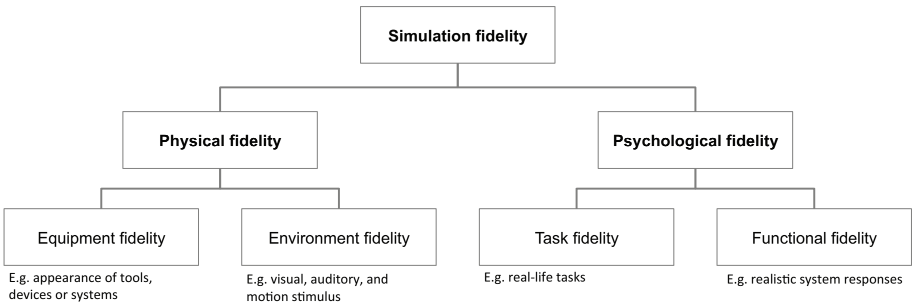

Figure 19. Simulation fidelity can be divided into a number of components and sub-components.

As for the fidelity of prototype systems, each of the fidelity components in a training simulation can be configured from low to high. When designing training simulations there are a number of factors that influence the overall configuration. First of all, the training goals affect the fidelity configuration. Drawing on Miller (1953), Alessi (1988) suggested that the degree of simulation fidelity should ideally correspond to the training stage of the learner. This implies that inexperienced persons can have high levels of skill training, even with low simulation fidelity. In addition, a cost-benefit evaluation of the simulation does play an important role; increasing the fidelity components beyond a certain level will not necessary produce the extra skill transfer needed to account for the added cost.

With the above mentioned similarities and differences a central question thus becomes: Can fidelity theories from training simulation research provide a guiding framework for the right level of fidelity in lab-based usability evaluations of mobile health care systems? This question will be discussed in Section 8.3.

4.5. Conclusions

The commonly used methods for evaluating usability of software are not directly transferrable to the health care domain, which is characterized by collaboration and mobility. Usability testing of mobile technology in healthcare consequently requires new ways of designing and performing the tests, as well as new techniques of recording user and system behavior.

A number of challenges still remain to be solved: How realistic should the simulation be? How can one collect data? How can one provoke user reflection? What kind of usability problems does one find with the simulation approach?

This chapter has provided the background knowledge necessary to understand the methods used in this thesis. It has also provided the motivation for the third research challenge:

(3) How should clinical simulations be planned and conducted to maximize the value and validity?

Next I will direct attention towards research methods relevant for research on doctor-patient communication, mobile point-of-care systems, and usability evaluations.

5. Relevant Research Methods

In the previous chapters the background and motivation for this thesis was presented. The aim of this chapter is to present relevant research methods used in research on doctor-patient communication, as presented in Chapter 2, and on design and evaluation mobile point-of-care systems as presented in Chapters 3 and 4.

5.1. Research strategies

There is a large number of research methods, most with various sub-variants. The strategy circumplex has categorized these into eight different research strategies.

Strategy circumplex

A number of different methods have been used in research on doctor-patient communication and on design and evaluation mobile point-of-care systems. To place these methods in a broader perspective, the *strategy circumplex* by McGrath (1995) is used (Figure 20). This framework and taxonomy structures eight strategies for gathering research information, although it was originally for studies on information systems. The eight different strategies described in the strategy circumplex are *laboratory experiment*, *experimental simulation, field experiment*, *field study*, *computer simulation*, *formal theory*, *sample survey*, and *judgment study*. The strategies are grouped into four categories: *experimental*, *field*, *theoretical*, and *respondent* strategies. A summary of all the strategies is given in Table VI.

For any research strategy there are three desirable criteria; (1) *generalizability* of the evidence, (2) *precision* of measurements, and (3) *realism* of the study context. However, these criteria are contradictory; one cannot maximize all criteria by using one strategy. This means that one should not rely on a single method, but triangulate methods by using a combination of several of them. In addition, each strategy is relative to two underlying dimensions; *concreteness* (concrete vs. abstract research setting) and *obtrusiveness* (obtrusive vs. nonobtrusive with regard to system being studied). Figure 20 also presents the strategies related to the criteria and underlying dimensions.

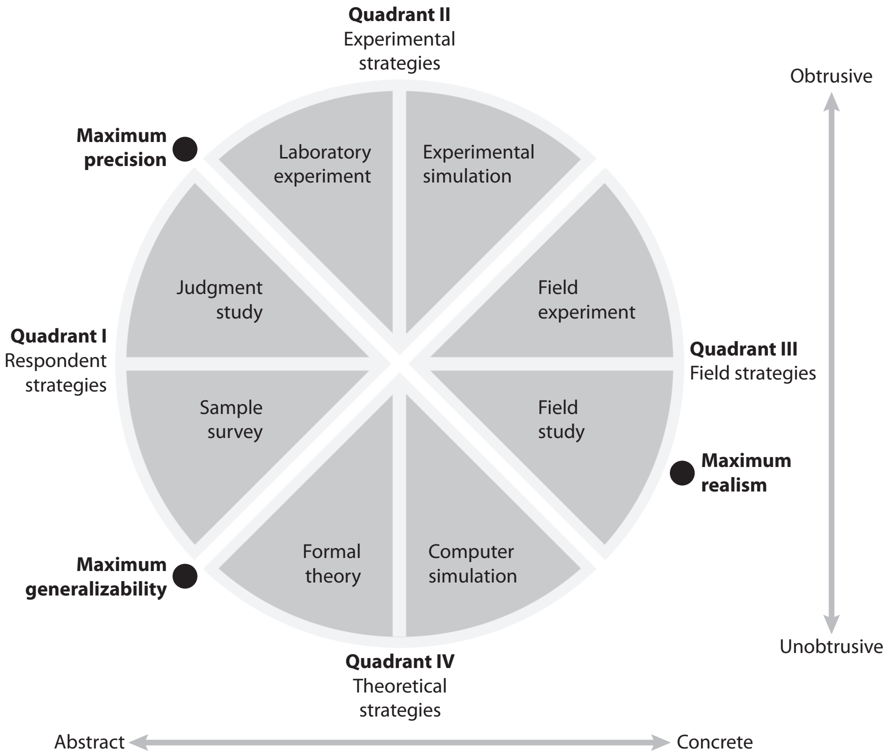

Figure 20. The strategy circumplex, adapted from McGrath (1995).

Table VI. Description and examples of methods presented in the strategy circumplex (McGrath, 1995) presented in **Figure 20**.

Research strategy	**Description**	**Example methods**	**Example studies from background sections**
Sample survey	Collecting data for estimating specific variables and how their relationship are distributed within a given population.	Public polls, questionnaires.	Houston et al. (2003)
Judgment study	Collecting information on a topic, or properties of stimulus.	Interview, focus group	McAlearney et al. (2004)
Laboratory experiment	Participants are introduced to a constructed situation or setting with predefined rules.	Conventional usability test	Kjeldskov and Skov (2006)
Experimental simulation	Combines the precision and control associated with laboratory experiments, with the realism of field studies.	Ground-based flight simulators	Dahl et al. (2008)
Field Experiment	On-site observation of a natural system that is manipulated to assess the effects.	Field-based usability evaluation	Pascoe et al. (2000)
Field study	Direct observations of natural systems, with minimal intrusion or disturbance of the system.	Case studies	Heath (1986)
Computer simulation	Non-empirical approach. Natural system represented in a computer model. The model simulates how changing parameters affect the real-world system.	Weather forecasting, business planning	None
Formal theory	Purely theoretical approach. The use of existing theories to formulate general relations among variables of interest.	General theories of behavioral and social sciences	None

When looking at the methods used in the studies presented in Chapter 2, the following is observed:

- Early studies on communication are based mostly on experimental strategies (Quadrant II), especially laboratory studies (e.g. Argyle and Cook, 1976).
- The majority of studies on doctor-patient communication make use of field studies, sample surveys and judgment studies (e.g. Heath, 1986; Houston et al., 2003; McAlearney et al., 2004)

- Otherwise, there is little use of experimental strategies (e.g. Dahl et al., 2006)
- There is no use of theoretical strategies.

Research through design

Research through design is not a research strategy such as those described above, but rather a *research approach* within Human Computer Interaction (HCI) that uses methods from design practice (Zimmerman et al., 2007). With this approach researchers make prototypes, products, and models. These artifacts are used to materialize their understanding of a particular situation, to frame the problem, and to describe a preferred future state. The approach allows design researchers to address wicked problems (e.g. Rittel and Webber, 1973), i.e. problems that often arise in the social realm and are difficult to solve because of incomplete, contradictory, and changing requirements. Moreover, the focus is on constructing for the future, rather than understanding the present. One aim is to evaluate current technology and investigate how future products and services will affect people. Another is to create concrete research outcomes or artifacts that can translate the findings and bridge the gap between the HCI research community and the HCI practice community.

Zimmerman et al. (2007) formulate a number of evaluation criteria for design research within HCI:

(1) The *process* must provide enough detail to be reproduced,
(2) the contribution must be an significant *invention*,
(3) it must be *relevant*, meaning that the motivation, current situation, and preferred state, is documented, and
(4) it must be *extensible*, meaning that the community can build on the outcomes.

5.2. Analyzing doctor-patient communication

Based on the review of literature in Chapter 2, there are three promising ways of analyzing doctor-patient interaction and communication; (1) by using an *interaction analysis system* to quantify properties of communication, (2) by using *qualitative video analysis* to get detailed insight into human behavior, or (3) by applying a *grounded theory approach* to generate theory from the data.

Interaction analysis systems

Communication between physicians and patients are often analyzed using so-called *interaction analysis systems* (IAS). IAS is not computer software, but rather an observation instrument for the researcher to identify, categorize and quantify important characteristics of the doctor-patient communication (Ong, 1995). This is usually done by coding utterances with tags such as '[Doctor] asks open-ended questions', '[Doctor] gives information' or '[Patient] shows concern or worry'. The codes can then be used as a basis for statistical analysis.

There exist a range of different IAS (Ong, 1995), each focusing on specific areas of doctor-patient communication. Some focus on treatment by capturing instrumental (task focused) behavior, others focus on care by capturing affective (socio-emotional) behavior, while some focus on both. One of the most frequently used IAS is the *Roter Interaction Analysis System* (RIAS) (Roter and Larson, 2002).

The main drawback with IAS is that computer usage during interaction between doctors and patients has no place in the analysis systems. One exception is a RIAS study (Margalit et al., 2006), where parameters such as computer gaze time and level of active keyboard typing (light/moderate/heavy) where coded. However, those parameters were not an integrated part of RIAS, but rather tacked on the existing codes.

Video in qualitative research

Video-based studies of human interaction and conduct have in the recent years had a wide impact across social, cognitive and computing sciences (Heath et al., 2010). In health care, video-based studies have had particular impact on our understanding of the medical consultation and the relationship and collaboration between doctors and patients.

Examples of such findings are how patients:

- encourage doctors to show attention as they disclose symptoms (Heath, 1986).
- are sensitive to the use of computers in the consultation (Greatbatch et al., 1993; Heath and Luff, 2000).
- "transforms themselves from an active subject into an object of inspection and investigation" during the consultation (Heath, 2006).

Such findings require that human interaction, turn taking, and sequentiality are studied in detail. This requires the production of detailed transcripts of talk and action.

The main difference between qualitative video analysis and IAS (described in the previous subsection), is that the former strive for a deep understanding of human conduct, e.g. how people orient themselves or use tools and objects in social interaction. The latter has the main focus on the language. Further, while video analysis requires very detailed transcriptions and analysis of segments of talk, utterances and behavior, IAS allows the researcher to quickly tag entire conversations with predefined labels.

Turn-taking and sequentiality: As presented in Section 2.1, people use the "universal language" of *turn-taking* to organize conversations fluently. Turn-taking allows people to talk one at a time, to obtain talk-turns, to provide their utterances in allocated turns, and to minimize gaps and overlaps between turns (Sacks et al., 1974).

An utterance or action in a conversation is *context sensitive* and *context renewing*. This means that it cannot be understood sufficiently without reference to the context. The context includes the environment, the participants and the conversation history. In addition, the utterance or action adds to the body of context and influences the course of the conversation. The same action, a smile or a gaze, can produce different actions depending on the situation in which it occurs (Heath et al., 2010).

The knowledge above allows a researcher to analyze talk and visible conduct, and make precise assumptions about why participants are behaving in a particular way, why they use objects in the environment, and why they interact with other people.

Transcribing talk and action: When analyzing human talk and conduct, it is necessary to produce detailed transcripts of voice and behavior to accompany and illuminate the data. This enables the researcher to explore the sequentiality of participants' actions, and to discover aspects of actions that otherwise would pass unnoticed. It is also a way to give other researchers insight into the data without providing the full video.

In the sociological tradition of qualitative video analysis, detailed textual transcripts are often produced and used as a basis for the analysis. The information detail in these transcripts is high and can be hard to interpret by researchers outside the domain of sociology. Heath and Hindmarsh (2002) have used an intelligible transcription method where speech and action are mapped onto a timeline. This allows the researcher to get a deep understanding of the interactions and sequentiality in the video fragment.

As seen in Figure 21, the transcripts can be very detailed and capture the subtle nuances of talk, intonation and utterances. It requires exacting training in the sociological research tradition and a background in conversation analysis both to transcribe and interpret these subtle nuances.

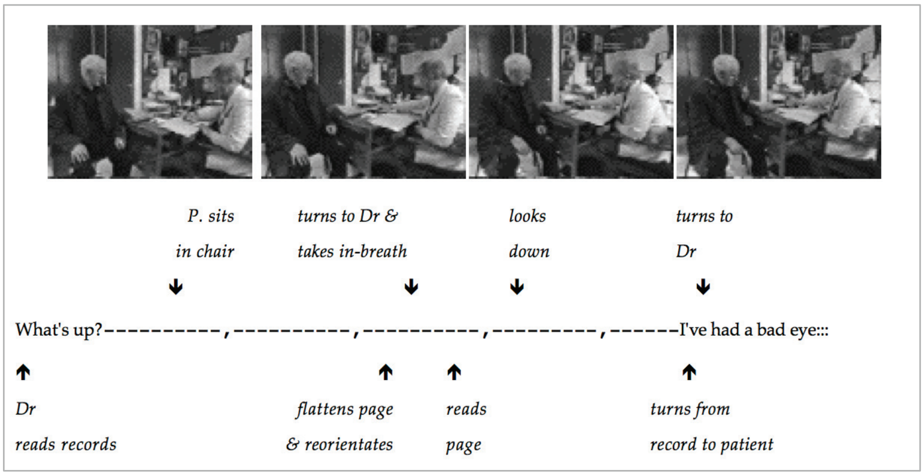

Figure 21. Example of transcript that capture the subtle nuances of talk, intonation and utterances (figure from Heath et al., 2002)

Method for qualitative video analysis: The method proposed by Heath et al. (2010) for analyzing video recordings of human conduct is as follows:

- Collect audio-visual data, with special attention on the sound and video quality.
- Preliminary review of data, where interesting video fragments are identified.
- Substantive review of data, with focused review, repeated viewing, and detailed transcription of identified fragments.
- Analytic review of data, where talk and visible conduct are analyzed with basis in the transcripts.

Grounded theory

Grounded theory describes how to develop theory based on empirical data (Glaser and Strauss, 1967). In contrast to traditional research, where one starts with a research hypothesis before one collects data, this method starts with the data collection before analyzing and systemizing the data and building a theory – like a reverse engineered hypothesis.

The sense-making of the empirical data is done by marking key points with *codes*. The data can be field notes, transcripts, or any other kind of data, even quantitative. Codes with similar content are then grouped into *concepts*. Similar concepts form *categories*, which are used to develop a theory. The codes, concepts categories and theory are constantly compared and modified as the researcher moves back and forth between them and the data. The process can be compared with the iterative nature of the human centered design process presented in Section 3.1.

Moreover, grounded theory is seen as a systematic approach to analyze qualitative data, in contrast to many other qualitative methods. This has contributed to the acceptance of qualitative methods in applied social research (Thomas and James, 2006). However, grounded theory is claimed to oversimplify complex meanings and interrelationships. It is also claimed to constrain analysis by prioritizing procedure before interpretation, and depending upon inappropriate models of induction. This can make the explanations and theories equally inappropriate (op. cit.).

5.3. Quality of research

In the same way as there are a number of quality criteria for mobile point-of-care systems (cf. Section 3.4), there are also a number of evaluation criteria for research. Some of those are described below.

Validity

Validity refers to the accuracy of the results. There are different kinds of validity, each addressing different methodological issues (Robson, 2002). To explain them, the first research question is used as an example (cf. Section 1.1), where the relationship between two variables, *mobile system usage at the point of care situation* and *the quality of doctor-patient communication* could be measured.

- *Conclusion validity* questions whether the method used shows a relationship between the two variables that are studied. An example from this thesis: Can the methods used show if there is a relationship between mobile EPR usage and doctor-patient communication?
- *Internal validity* questions whether the method used demonstrates a casual relationship between the two variables or not. Using the example above: It could be that it is not mobile device usage that causes negative effects on doctor-patient communication. It could just as well be the personal characteristics of the physicians, for example their empathy or multi-tasking abilities.
- *Construct validity* refers to whether the methods measure what they intended to measure. For example, are the methods used able to confidently measure the relationship between mobile EPR system usage and doctor-patient communication?
- *External validity* (also known as *generalizability*) questions whether the relationship found can be generalized to other settings (or people, times or places). For example, can any new knowledge on effects of mobile point-of-care systems on doctor-patient communication be generalized to other hospitals in other countries, or maybe even other domains, such as mobile usage in any social setting?

Ecological validity, relevance and reliability

In addition to validity, there are three other important criteria that are relevant for assessing the quality of research:

- *Ecological validity* concerns whether the research is representative for what happens in the real world or in real-life situations (Brewer, 2000). For example, in what degree is the research setting resembling a ward round?
- *Relevance* concerns whether the phenomenon actually happens in the real world and whether the findings are potentially useful and applicable for solving real-life problems. For example, can the findings be used to design mobile point-of-care systems that have a positive effect on doctor-patient communication?
- *Reliability* is “the extent to which a measurement gives the same answer whoever and whenever it is carried out” (Kirk and Miller, 1986). If the research in the example above were reliable, another researcher would find the same relationship between mobile devices and doctor-patient communication if repeating the study at a later time. However, it does not necessary mean that the answer is valid.

In addition to the evaluation criteria above, there are a number of relevant perspectives that are relevant in evaluating research. One such perspective is Klein and Myers’ (1999) set of principles for evaluating interpretive field studies in information systems. However, these principles are limited to interpretative field studies, such as in-depth case studies or ethnographies.

5.4. Conclusions

There are a number of research methods used for doctor-patient communication, where field studies, sample surveys and judgment studies are most common. In addition, there are three promising ways of analyzing doctor-patient interaction and communication; (1) by using an *interaction analysis system* to quantify the properties of communication, (2) by using *qualitative video analysis*, or (3) by applying a *grounded theory approach*. Further, *research through design* is an interesting approach for investigating how new technology will affect people. A number of criteria for evaluating research were presented. These criteria need to be discussed later to establish the validity of the research conducted. Next, I will present the research design for this study.

6. Research Design

At this point the background and motivation for this thesis have been presented, as well as relevant research methods based on a study of what has been done in the literature. Now it is time to present my own research. The aims of this chapter are to present and explain the general research design of the present work, and to explain how the data are analyzed. For further details on the specific research designs, see the research papers in Part II.

6.1. Analyzing the problem

The research questions and some external constraints provide guidelines for the selection of methods for this thesis.

The research aim of this work was introduced in Section 1.1, and is included below for completeness:

> The overall research aim for this thesis is to explore properties of mobile point-of-care systems in hospitals that are important for doctor-patient communication in ward rounds.

This aim calls for a research approach that focuses more on the properties of the mobile systems than the doctor-patient communication. It is, however, important to fully understand the mechanisms behind this communication. Therefore the first research question is:

> How do mobile point-of-care systems affect doctor-patient communication in ward round settings?

Answering the first research question forms a good basis for making technology better suited to support the communication. But making technology better calls for an informative and explorative approach, rather than a summative one where the status quo is described. The second research question sums this up:

> How should mobile point-of-care systems be designed to support the doctor-patient dialogue?

As the reader will learn, the selection of research methods is not straightforward because of a number of external constraints.

Current methods are not suitable

Current research on doctor-patient communication employs research strategies that are largely based on field studies, together with judgment studies (i.e. interviews and focus groups) and sample surveys (cf. Chapters 2 and 5). Ideally the current research should be based on field studies, since many effects of mobile point-of-care systems on communication are likely to be embodied, implicit and subconscious for the participants in the ward round. However, the five reasons below suggest that a different approach is taken:

1. **No mobile systems in use.** The current research is ahead of its time, at least in a Norwegian context. Although the adoption of EPR systems in primary and secondary care is complete, there are no mobile EPR systems currently in use in Norwegian hospitals (cf. Section 3.3). Given the lack of mobile systems in use, the research presented in this thesis needs to take a quite different research approach than the studies presented in Chapter 2.

2. **Prototype systems threat patient safety.** Since there are no mobile EPR systems currently in use, prototype systems need to replace the real systems in the field. However, any use of prototype systems in the field can impose a threat to patient safety. This disqualifies field-based research strategies when real patients are present.

3. **Ethical approvals are difficult to obtain.** Field studies in hospitals, involving employees and patients, require approval from ethical committees. In particular when patients are involved in the studies, strong regulations are imposed on what kind of research can be done and recorded.

4. **High quality video recordings can be challenging.** The use of video and audio recordings in the field can be complicated due to patient information confidentiality. In addition the parties in a real-life ward round may find the use of cameras disturbing and obtrusive. This may affect the communication.

5. **Ward rounds are hard to compare.** Point-of-care situations are heterogeneous, where few cases are similar. This makes direct comparisons between different ward rounds and actors difficult in the field.

These reasons call for a different approach than field studies. Judgment studies and sample surveys are candidates, but they will fail to capture the embodied, implicit and subconscious aspects of communication.

6.2. Choice of research strategy

One promising research approach is to look towards simulation-based usability evaluations and training simulations (cf. Chapter 4). Such simulations attempt to recreate real work situations in a controlled laboratory setting, where participants are asked to play out realistic work scenarios. Can this approach answer the first research question without using field studies of real wards round in the hospital?

Simulation-based usability evaluations versus field studies

The use of lab-based usability evaluations is subject to a number of questions and critiques: Why are field studies not being used in the first place? Can the lab really be a valid substitute for the real world? As clarified below, the lab-based approach has both strengths and limitations compared to the field.

1. **Prototypes replace mobile systems.** In the lab, the researcher does not need to have fully functional system, but can get reliable data from the use of unfinished prototype systems in a controlled lab setting. The prototypes can have different fidelities, ranging from paper-mockups to high-fidelity prototypes.

2. **Prototype systems in a lab are safe.** The approach that observes the effects of mobile prototype systems on doctor-patient communication in a lab-based environment makes sense; hospitals should not introduce systems before exposing the system to real users and before knowing the consequences of the introduction. In the lab the researcher can safely introduce different prototypes of mobile point-of-care systems, and observe how they affect the participants in a protected environment with no potentially harmful effects.

3. **Ethical approvals are easy to get.** In the lab, ethical approvals are fairly unproblematic. Test subjects volunteer to participate and no real patients are used. Hence is patient confidentiality regarding video data recordings of patients not generating a problem for the researcher.

4. **Access to high-quality video recordings.** In the lab, detailed video and audio recordings from multiple angles are easy to set up and record. To achieve the same quality in the field can be difficult as one has less control over the environment.

5. **Ward rounds are easy to compare.** In the lab the researcher has immediate access to relevant and identical use situations, and can directly compare data from the different participants.

Substituting the real world with role play requires a more extended discussion. The challenge is to make the setting realistic enough, so that the doctors and nurses accept the illusion of being in a real hospital ward with real patients, and behave thereafter.

Drawing on work by Seland (2010) there is reason to believe that participants *are* able to accept role play as realistic. The acting skills of most participants in lab-based role-play sessions are able to amaze professional drama instructors and even fool camera crew to believe they are filming a real world documentary, despite the lack of professional actor training (Seland, 2010, p. 113). One key success factor is that they enact a role they are familiar with, or even better, they enact themselves.

Seland (2010) suggests two kinds of reality checks whether the participants accept the illusion: The simplest way is to ask them. Did they feel that the simulation was realistic and close to the way they work? The other way is to observe whether they stick to their role as a clinician during the simulation and whether they avoid overacting.

Primary research method: Simulation-based usability evaluations

Based on the discussion above, the main method used in this thesis will be *simulation-based usability evaluations* (cf. Sections 4.3 and 4.4). In these evaluations clinicians and trained patient actors will role-play ward rounds in a simulated hospital environment. The physician performs ward rounds as they do in the real world. The exception is that they now are equipped with mobile electronic (or paper-based) information devices that are used as supportive tools in their meeting with the patient. These *role-plays* will be observed, recorded and analyzed. The recordings will be treated as if it were data from the field.

The research approach taken needs to address a number of data collection and validity issues, especially concerning ecological validity (i.e. how well the participants are able to accept the simulation as real). Therefore is the last research question formulated as follows:

> How should usability evaluations with multiple users be planned and conducted to maximize the value and validity of the results?

According to the strategy circumplex (McGrath, 1995), the approach taken in this thesis is classified as *experimental simulation* (cf. Figure 20 in Section 5.1). While a field study maximizes realism and sacrifice control, an experimental simulation is a compromising approach where one attempts to achieve sufficient realism while maintaining necessary precision and control over the research setting. Still, the experimental simulation will never achieve the same realism as a field study. This implies that an error of unknown size is made, and in addition will it pose a number of validity issues. This and other limitations are further discussed in Chapter 8.

Secondary method: Interviews

The informative and explorative nature of this research calls for a deeper understanding of the participants and their views on the use of mobile technology in ward rounds. This knowledge of the participants' experience can best be achieved by interviewing them after having experienced it. Therefore, post-test interviews will be conducted, where various aspects of mobile point-of-care systems and effect on doctor-patient communication are discussed. Drawing on Seland (2010), the interviews will also provide the participants' perceptions of the realism of the experiments. The interviews can therefore be used as reality checks on whether the participants accept the illusion of being in a real ward round.

6.3. Study design

The empirical results in this thesis are based on four different simulation-based usability evaluation studies conducted in a usability laboratory. The lab is designed as a section of a hospital ward. All four evaluations were conducted in a simulated context-of-use replicating a hospital environment (see the subsection above). In total, 180 ward rounds with 36 clinicians were conducted in the studies.

Support methods

In addition to the simulation-based usability evaluations, the research conducted has used a number of supportive research methods, where representative end users, such as doctors, nurses and patients, have been involved:

- *Field studies* where doctors and nurses have been followed in real ward rounds to understand how they use the paper chart and how they work without mobile technology support.
- *Interviews, focus groups* and *group interviews* with doctors, nurses and patients before and after the simulation-based usability evaluations to understand user needs and to get feedback on how mobile technology can play a role in future point-of-care situations.
- *Participatory design workshops* where new technology has been prototyped together with the participants, including *role-play* where they have imagined future use of this technology.

- *Surveys* to get data on demographics and computer experience from the participants.

Although not all of these methods (and results) have been explicitly reported in the papers presented in Part II, they have been important to understand the domain, the users, and their needs.

As presented in Chapter 5, the research strategies used are spread around the circumplex area, see Figure 22. Two of the strategies are heavily used (emphasized), while three strategies are less used and three strategies are not used at all (faded out). Given that observations are open to bias error, the use of multiple research strategies open up for triangulation of the data. This allows for greater precision, realism and generalizability.

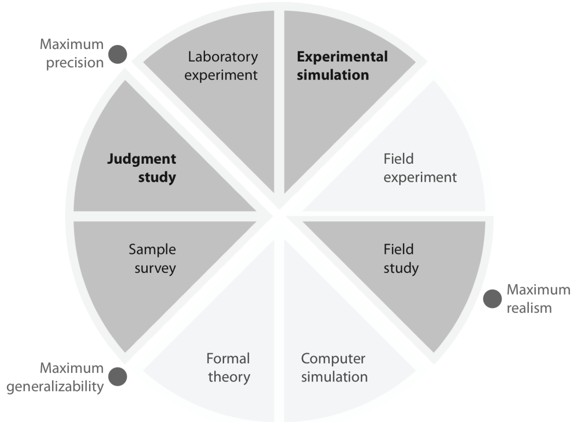

Figure 22. A number of research strategies are used in this research design. Heavily used strategies are in bold while the others are used less. Faded out strategies are not used (Figure is adapted from McGrath, 1995).

Overall conceptual view

Figure 23 shows a conceptual view of the research setting, which includes the technical facilities of the usability laboratory, the physical and social context of use, and the evaluated product or prototype. The details of the study designs can be found in the research papers in Part II, but the general design is described below.

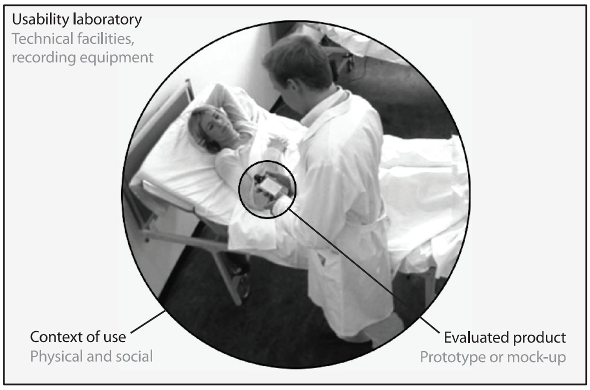

Figure 23. Conceptual view of the research setting (illustration from *Paper 3*)

Usability laboratory

The usability laboratory at the Norwegian Research Centre for Electronic Health Records (NSEP) has been central in this research. Completed in 2005, it has been used for full-scale usability testing of a number of health information systems in various stages in the design process, ranging from experimental lo-fidelity prototypes to practically finished systems. The lab is currently one of the most advanced installations for full-scale testing of health information systems in the world. Apart from the NSEP lab, there are currently only a limited number of usability laboratories for developing and evaluating health care (Beuscart-Zéphir et al., 2007).

The laboratory consists of an 80 m^2 room with configurable walls that allows full-scale testing of different hospital settings (Figure 24). The lab area is fully equipped with patient beds and other furniture to mimic parts of a real-life hospital (Figure 25, *right*). Moreover, the lab is equipped with remotely controlled dome cameras and microphones, as well as mirroring software that allows for wireless screen capture of the mobile device. Adjacent to the lab area there is a control room area with recording equipment for video and audio, and advanced software for video analysis (Figure 25, *left*). The lab setup allows real time integration of video streams, audio channels and screen captures from a number of cameras, microphones and devices – all into a single video clip (Figure 26). The collection of data sources in one video stream simplifies the subsequent analysis.

The lab and its benefits and limitations are further described in Klingen (2005) and in *Paper 1: Methodological and practical challenges*.

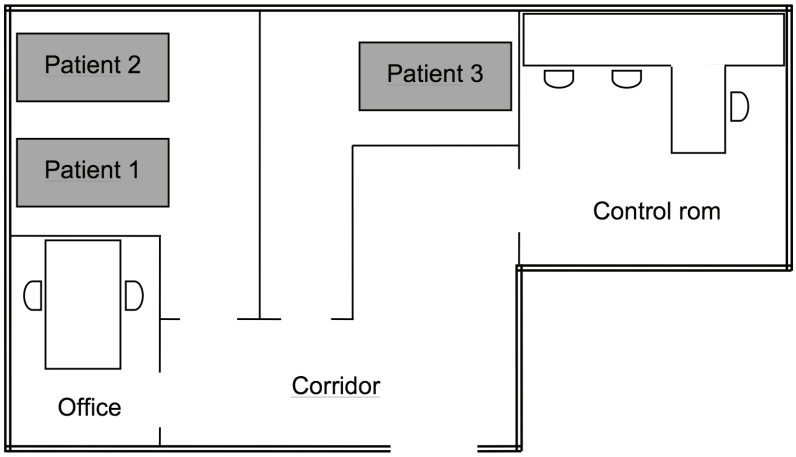

Figure 24. Floor plan of the usability laboratory used in the studies (adapted from Bjønnes, 2007).

Figure 25. The control room area (*left*) and the lab area (*right*) of the NSEP usability laboratory (Right photo by Terje Røsand)

Figure 26. A typical videoframe from a usability evaluation, showing the graphical user interface of the system and a number of video images from the lab.

Context of use

In addition to the physical environment, the context of use consisted of patients. Realistic patient cases and scenarios were developed in close cooperation with domain experts. For all studies the patient actors were given more or less detailed instructions on how to behave realistically according to the patient scenarios. A typical patient scenario is provided below (from Study 3):

> *The patient is a 44-year-old woman. She is hospitalized with an acute episode of Crohn's disease for two days. The current treatment was started right after admission of the patient. It comprises 1) Prednisolon (Prednisolone), 20 mg, tablet, twice a day, and 2) Salazopyrin (Sulfasalazine), 500 mg, tablet, three times a day.*
>
> *During the ward round the patient discloses to the physician that she has developed an itching rash over her entire body. She remembers that she had a similar reaction to some antibiotic, but does not remember its name.*

The purpose of the patient scenarios was (1) to provide a realistic clinical situation, (2) to employ the physicians' professional experience and practice, (3) to reduce the scope of the consultations, (4) to reduce variations in the outcome, and (5) to make sure the physicians had at least one interaction with the prototype (or the paper chart) during the visit, triggered by the patients' complaints and concerns.

Evaluated prototypes

The prototypes were working systems with medium to high fidelity. They allowed the clinicians to respond to the course of the consultation by performing necessary changes in the patient record. Details on the prototypes are described in the research papers in Part II.

Conducted usability evaluation studies

Four simulation-based usability studies were conducted, where several variants of mobile point-of-care systems were evaluated. The studies were comparative in the sense that each study compared different versions of the prototype system with a baseline (often the currently used paper-based chart). An important supplement to the studies was the post-test interviews, where physicians and patients (and nurses in two of the studies) were interviewed about their experiences, opinions and ratings of the mobile systems.

I have had a role of varying importance and workload in all the studies, ranging from being responsible for the study, to participating as a patient actor. The studies are summarized in Table VII, while their relation to the papers are presented in Table VII. For further details on the study designs, see the research papers in Part II.

Table VII. Summary of the four evaluation studies used in this thesis

		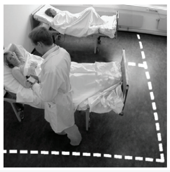	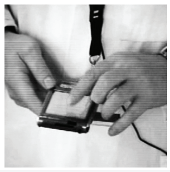	
Evaluation study:	**Study 1.** Using handhelds as input device for Patient Terminal (PT)	**Study 2.** Sensor based interaction techniques for point-of-care EPR access	**Study 3.** Comparing paper and PDA-based interaction techniques	**Study 4.** New mobile point-of-care EPR system for hospitals
Author's role:	Responsible for the study	Similar research design as in study 1	Co-responsible for the study and advisor	Patient actor. Partly involved in planning
Solutions evaluated:	7 solutions (PDA + PT) 1 baseline (PT only)	2 location-based and 2 token-based solutions	Paper-based baseline and 3 PDA-based solutions	Paper-based baseline and mobile EPR solution
Participants:	5 pairs consisting of physician and patient actor	5 nurses	14 physicians, 4 patient actors	8 physicians (and 4 nurses)
Patients per scenario:	1 patient	3 patients	1 patient	3 patients
Total no. patient consultations	40 consultations	60 consultations	56 consultations	24 consultations
Year of study:	2005	2005	2007/2008	2008
Key paper:	Alsos and Svanæs, (2006)	Dahl and Svanæs, (2007)	Paper 5, Paper 6	Paper 4

Table VIII. Relations between the four studies and the six papers. A dot means that the paper is based on empirical data from the corresponding study.

	Research papers							
Studies	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Study 1. Using handhelds as input device for patient terminal	•	•	•				•	•
Study 2. Sensor based interaction techniques for point-of-care EPR access	•	•	•				•	
Study 3. Comparing paper and PDA-based interaction techniques		•	•	•	•	•	•	•
Study 4. New mobile point-of-care EPR system for hospitals				•				

6.4. Analysis

Many of the findings in this thesis are based on retrospective analysis of data from the lab studies and usability evaluations. Some of the studies were originally designed for another purpose than the particular findings presented this thesis. The aim was often to evaluate the mobile system and the design ideas. However, by analyzing the data across different studies, and viewing the data from new angles, additional insight has been gained on how using the mobile system has affected the dialogue between the doctor and patient.

Since the patient actors were not real patients, the focus of the analysis has been on the non-verbal aspects of communication with the mobile device, and less attention has been given on the dialogue between the two. This makes video analysis highly relevant, while the application of IAS is less relevant (and therefore not used). The post-test interviews were subject to a grounded theory analysis.

Video analysis

Using the method for qualitative video analysis as presented in Section 5.2 (Heath et al., 2010), it was possible to get detailed data on how physicians used the mobile devices during the ward round, and how this usage affected verbal and non-verbal aspects of communication, as well as how it affected the collaboration between all the actors in the ward round.

The procedure for the video analysis was as follows: High quality video and audio data were collected in the evaluations. Then, interesting video fragments were identified based on the research questions. These video fragments were repeatedly viewed, while talk and action in the fragments were transcribed. After that, the different actors' talk, pauses and gaps were transcribed and mapped onto a timeline (Figure 27).

This is a less rigorous version of Heath's transcription method. The benefit of the lightweight method used is absolute mapping of talk to a timeline and easier interpretation for untrained sociologists. The drawback is that it loses much of the fine details of utterances, pauses and pronouncements. However, to display evidence of simple interactions, I have found this transcription method sufficient.

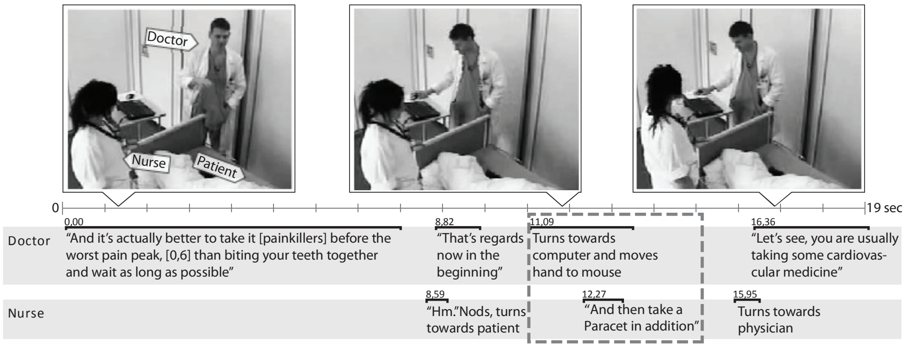

Figure 27. Example transcription of video fragment from *Paper 6*. The transcription method is based on Heath et al. (2010), but is less rigorous regarding the fine details of talk.

Interview analysis

A lightweight approach of *grounded theory* (Glaser and Strauss, 1967) has been used to analyze the interview data from some of the studies: Data from the physician interviews and patient focus group were first fully transcribed verbatim. The transcriptions were imported into NVIVO software for qualitative data analysis. With this software the interview data were analyzed by inductively identifying text segments and marking them with thematic 'codes' that highlighted certain aspects of the data, using techniques inspired by a grounded theory approach. During this analysis, the meanings and definitions of each code were continuously updated as new aspects were revealed in the material. Using the software for qualitative data analysis, reports were generated, sorted by code and linking interview extracts from the interviews. On the basis of these reports the main themes that were reported were sorted according to how they answered the research questions.

6.5. Conclusions

This study calls for an informative and explorative research approach. On the basis of external constraints described above, simulation-based usability evaluation was selected as the primary method. Interviews were chosen as the secondary research method.

In the next chapter, summaries of the papers that add up the results of this thesis will be presented.

7. Results

In the previous chapter, the methods used in this thesis were presented. This chapter summarizes the papers that contain the results from the studies conducted.

The research work has been published as four journal papers and four conference papers. An overview of the papers, the main contributions, and the authors' contributions herein are presented in this chapter. The chapter serves as a short presentation of the papers, their main findings and their relation to the research questions of this work.

7.1. Papers

Below, the papers that represents the results of this thesis are summarized. Each summary describes the following:

1. The authors and their contributions to the paper.
2. The full paper title.
3. Where the paper was published.
4. What was already known about the topic.
5. What this study added to our knowledge.
6. The paper's relation to the research questions.

Each of the eight published papers has been peer-reviewed, i.e. accepted by other researchers as providing a significant contribution to the body of knowledge. The papers are reprinted in full length in Part II of this thesis with the permission from the editors. The paper summaries are ordered in suggested reading order. Those relating to methods are presented first. In addition, each paper has been given an appropriate short title, which is used in cross-references.

The summaries of the papers presented in this section are:

Paper 1. Methodological and practical challenges.
Svanæs, D., Alsos, O. A., Dahl, Y. *Usability testing of mobile ICT for clinical settings: Methodological and practical challenges*. International Journal of Medical Informatics, *79*(4), 2010, Elsevier.

Paper 2. Techniques and considerations for lab-based usability evaluations.
Alsos, O. A., Dahl, Y. *Toward a Best Practice for Laboratory-Based Usability Evaluations of Mobile ICT for Hospitals.* Proceedings of NordiCHI 2008, ACM.

Paper 3. Fidelity considerations.
Dahl, Y., Alsos, O. A., Svanæs, D. *Fidelity Considerations for Simulation-Based Usability Assessments of Mobile ICT for Hospitals.* International Journal of Human Computer Interaction, *26*(5), 2010, Taylor & Francis Group.

Paper 4. Role of user interface and form factor.
Alsos, O. A., Das, A., Svanæs, D. *Mobile Health IT: The Role of User Interface and Form Factor on Doctor-Patient Communication and Collaboration.* To appear in International Journal of Medical Informatics (accepted 13 September 2011).

Paper 5. Effects of mobile devices in ward rounds.
Alsos, O. A., Dabelow, B., Faxvaag, A. *Doctors' concerns of PDAs in the ward round situation: Lessons from a formative evaluation study.* Methods of Information in Medicine, *50*(2), 2011.

Paper 6. Important usability factors for point-of-care systems.
Alsos, O. A., Dabelow, B. *A Comparative Evaluation Study of Basic Interaction Techniques for PDAs in Point-Of-Care Situations.* Proceedings of Pervasive Health 2010, IEEE.

Paper 7. Secondary user experience.
Alsos, O. A., Svanæs, D. *Designing for the Secondary User Experience.* Proceedings of Interact 2011, Springer.

Paper 8. Card Ranking.
Alsos, O. A., Dahl, Y. *Ranking for Reflection: The Application and Added Value of Picture Cards in Comparative Usability Testing.* Presented at Yggdrasil 2008 [available at http://bit.ly/paper8].

Paper 1: Methodological and practical challenges

Authors:	Dag Svanæs, Ole Andreas Alsos and Yngve Dahl.
Full title:	Usability testing of mobile ICT for clinical settings: Methodological and practical challenges.
Published in:	International Journal of Medical Informatics, *79*(4), 2010, Elsevier.
Authors' contributions:	Svanæs led the writing process. Alsos and Dahl designed the studies, collected and analyzed the data, and contributed in the writing process.
What was already known on the topic:	Clinical work in hospitals is information and communication intensive and highly mobile. Health workers are constantly on the move in a highly event-driven working environment. Most current Electronic Patient Record (EPR) systems only allow for access on stationary computers, while future systems will also allow for access on mobile devices at the point of care. While much is known about how to do usability testing of stationary EPR systems, less is known about how to do usability testing of mobile EPR solutions for use at the point of care. Few usability laboratories allow for testing in full-scale replications of hospital environments.
What this study added to our knowledge:	The usability of mobile EPR systems is to a large extent determined by factors that go beyond that of the graphical user interface. These factors include ergonomic aspects such as the ability to have both hands free; social aspects such as to what extent the systems disturbs the face-to-face interaction between the health worker and the patient; and factors related to how well the system integrates with existing work practice. To be able to measure usability factors that go beyond what can be found by a traditional stationary user interface evaluation, it is necessary to conduct usability tests of mobile EPR systems in physical environments that simulate the work situation at a high level of realism. In order to get valid results from usability tests of mobile EPR systems, it is necessary to make sure that the use scenarios are realistic. This often means that the tests must be run as role-plays with multiple stakeholders as participants, e.g. physicians, nurses, and patients. Due to concerns of privacy, ethics, and the possible fatal consequences of error, usability tests of EPR systems can rarely be done in situ. To be able to get valid results from usability tests of mobile EPR solutions, it is therefore necessary to equip usability laboratories with full-scale models of relevant parts of the hospital environment. As the hospital is a very heterogeneous environment, such laboratories should allow for easy reconfiguration of the floor plan.
Relation to research questions:	"How should usability evaluations with multiple users be planned and conducted to maximize the value and validity of the results?"

Paper 2: Techniques and considerations for lab-based usability evaluations

Authors:	Ole Andreas Alsos and Yngve Dahl.
Full title:	Toward a Best Practice for Laboratory-Based Usability Evaluations of Mobile ICT for Hospitals.
Published in:	Proceedings of NordiCHI 2008, ACM.
Authors' contributions:	The paper was written by both Alsos and Dahl. Alsos designed collected and analyzed data from two of the three experiments analyzed, while Dahl was responsible for the last.
What was already known on the topic:	Getting access to and performing usability evaluations in real clinical situations may be difficult in practice as they may have an obtrusive effect on ongoing work. The issue of patient information confidentiality may also prevent video and audio recording of observations. Conventional laboratories intended for controlled desktop-based usability evaluations are unsuited for reconstructing the rapidly changing conditions of hospital work. Producing valid results on the usability of mobile ICT for hospitals is dependent on the simulated physical and social context in which the evaluation takes place.
What this study added to our knowledge:	The usability of mobile ICT designed to support clinical work, is closely dependent on physical and social aspects of the care situation. For optimal cost-benefit, the physical environment, prototypes, and scenarios should be designed with just enough realism related to the research questions asked. Multiple design alternatives, smart interviewing techniques, and representations of prototypes available during interviews can encourage user reflection and inform system design. Non-intrusive recording techniques from multiple perspectives can provide a more valid and precise understanding of physical and ergonomic aspects of mobile designs.
Relation to research questions:	"How should usability evaluations with multiple users be planned and conducted to maximize the value and validity of the results?"

Paper 3: Fidelity considerations

Authors:	Yngve Dahl, Ole Andreas Alsos and Dag Svanæs.
Full title:	Fidelity Considerations for Simulation-Based Usability Assessments of Mobile ICT for Hospitals.
Published in:	International Journal of Human Computer Interaction, *26*(5), 2010, Taylor & Francis Group.
Authors' contributions:	Dahl led the writing process where Alsos was involved, both in planning, writing and reviewing phases. Alsos and Dahl provided the empirical data for the study. Svanæs provided feedback and comments throughout the entire writing process.
What was already known on the topic:	The usability of mobile ICT that supports clinical work is likely to depend on factors beyond the graphical user interface (GUI) and software solutions, including physical and social aspects of the use situation. Such external factors cannot be addressed through conventional usability testing in laboratories that simulate office environments. Training simulation research often describes fidelity as a multi-dimensional concept, encompassing various aspects of the research setting. In simulation-based skill training various fidelity dimensions are often tailored to fulfill specific goals.
What this study added to our knowledge:	Fidelity theories from training simulation research can be applied as a guiding framework for composing targeted usability evaluations of ICT for complex use settings, such as hospitals. Evaluators need to carefully consider the fidelity of the research setting vis-à-vis the actual performance context. Consultants from health care should be consulted in this process. For simulations to work as an effective tool in the design process, it is critical to identify the right level of simulation fidelity. Similar to the case for training simulations, the fidelity of simulation-based usability assessments can be adjusted to achieve targeted trials that help participants focus on specific aspects of the simulation experience. The simulation acceptance model gives a conceptual view of the factors that influence the extent to which a simulation experience evokes commitment and engagement among participants. This model can be used as a guiding framework for creating evaluations with just enough realism.
Relation to research questions:	"How should usability evaluations with multiple users be planned and conducted to maximize the value and validity of the results?"

Paper 4: Role of user interface and form factor

Authors:	Ole Andreas Alsos, Anita Das and Dag Svanæs
Full title:	Mobile Health IT: The Role of User Interface and Form Factor on Doctor-Patient Communication and Collaboration
Published in:	To appear in International Journal of Medical Informatics (accepted 13 September 2011).
Authors' contributions:	The paper was written by Alsos. Das and Svanæs provided empirical data from one of the two experiments described. In addition they provided feedback and comments on the paper.
What was already known on the topic:	In primary care, computer usage can have a negative impact on the communication and collaboration between the doctor and the patient. It becomes a third party in the doctor-patient dialogue and may suppress sensitive patient disclosure. Awareness of each other's actions is an important aspect of successful collaboration between clinicians and their patients. People intentionally and unintentionally configure awareness to support collaboration by using artifacts, posture, or nonverbal communication. Mobile devices are becoming more and more common in point-of-care situations for accessing and recording patient related information into electronic patient records (EPR). However, little is known about how such devices support or hinder aspects of doctor-patient collaboration. As information devices in hospitals move from paper-based to digital media, some affordances are lost, while new affordances arise.
What this study added to our knowledge:	The user interface and the physical form factor of a mobile point-of-care system are important elements for successful communication and collaboration between doctors and patients. Both elements need to be carefully designed so that physicians can use the devices to support face-to-face dialogue and nonverbal communication, and to make their actions visible for patients. The ability to facilitate the doctor-patient collaboration is an important usability factor in the design of mobile EPR systems, and should become a testable usability requirement.
Relation to research questions:	"How do mobile point-of-care systems affect doctor-patient communication in ward round settings?" "How should mobile point-of-care systems be designed to support the doctor-patient dialogue?"

Paper 5: Effects of mobile devices in ward rounds

Authors:	Ole Andreas Alsos, Benjamin Dabelow and Arild Faxvaag
Full title:	Doctors' concerns of PDAs in the ward round situation: Lessons from a formative evaluation study
Published in:	Methods of Information in Medicine, *50*(2), 2011.
Authors' contributions:	Alsos wrote the paper. Faxvaag contributed in the writing process, in particular to relate the findings into a medical context. Alsos and Dabelow planned and conducted the experiments for the study. In addition, Dabelow provided general feedback and comments in the writing process.
What was already known on the topic:	It has been shown that the use of stationary computers in the consultation room influences how patients perceive the quality of the consultation. Also, doctors' use of handheld computers might influence their abilities to commit themselves to the dialog with patients. Some physicians think that handhelds used bedside is a disturbing element in the conversation with the patient. Moreover, studies report that patients dislikes the idea of handhelds in the examining room
What this study added to our knowledge:	Despite the many benefits, physicians are worried about using handheld point-of-care systems in ward rounds because the device draws their attention away from the dialogue with the patient. Usage at the point-of-care comes with the increased risk of distractions, reduced ability to communicate non-verbally to the patient, and poor transparency of actions, which makes it harder for the patient to see what is going on. This can cause a negative patient experience. Designers of point-of-care systems need to be aware of, and address, the problems with PDAs and learn from the affordances of paper charts.
Relation to research questions:	"How do mobile point-of-care systems affect doctor-patient communication in ward round settings?" "How should mobile point-of-care systems be designed to support the doctor-patient dialogue?"

Paper 6: Important usability factors for point-of-care systems

Authors:	Ole Andreas Alsos and Benjamin Dabelow
Full title:	A Comparative Evaluation Study of Basic Interaction Techniques for PDAs in Point-Of-Care Situations
Published in:	Proceedings of Pervasive Health 2010, IEEE
Authors' contributions:	Alsos wrote the paper. Dabelow contributed in the planning, writing and reviewing process. In addition, Dabelow planned and conducted the study in collaboration with Alsos.
What was already known on the topic:	While established guidelines and principles exist for the specification of GUIs, few such guidelines exist when it comes to choosing and specifying the interaction techniques used by the system. Decisions regarding interaction techniques are mainly based on quantitative measures. However, in healthcare there are other factors, social and physical ones, which are equally important for the overall usability of a mobile information system.
What this study added to our knowledge:	There are a number of factors that affects the overall usability and user acceptance of different interaction techniques for PDA-based point-of-care systems. The interaction technique need to (1) allow for flexible usage, (2) have good mapping between input and output controls, (3) should not be dependent on an additional tool such as a stylus or pen (which tend to get lost), (4) should be accurate and precise, (5) should allow for one-handed usage, and (6) should give tactile feedback. Despite a number of drawbacks, PDA-based systems have some qualities that make physicians willing to replace their paper-based medication systems. The input technique is an essential part of the interaction with the system. An awkward input technique may demand much of the physicians' attention. This will reduce their ability to attend the patient and may reduce the quality of the doctor patient dialogue
Relation to research questions:	"How do mobile point-of-care systems affect doctor-patient communication in ward round settings? "How should mobile point-of-care systems be designed to support the doctor-patient dialogue?"

Paper 7: Secondary user experience

Authors:	Ole Andreas Alsos and Dag Svanæs
Full title:	Designing for the Secondary User Experience.
Published in:	Proceedings of Interact 2011, Springer
Authors' contributions:	Alsos wrote the paper. Svanæs provided feedback and comments throughout the writing process.
What was already known on the topic:	Computer systems in hospitals are first and foremost designed for the primary users (i.e. the clinicians). The needs of the secondary users, those who are not using the system directly but are yet affected by it (i.e. the patients), are often overlooked.
What this study added to our knowledge:	When designing information systems in healthcare that have effects on people beside the primary user, the designer and requirements engineer must address the need of all types of end-users. This includes the needs of the secondary user, and implies that one has to design for the secondary user experience. Sometimes this implies that the designers deal with conflicting needs between the direct and indirect users. Approaches to improve the indirect user experience include (1) inviting indirect users to usability evaluations, (2) using the language of the indirect user, (3) providing a GUI tailored for the indirect user, (4) supporting non-verbal communication, and (5) giving system feedback to the indirect user.
Relation to research questions:	"How do mobile point-of-care systems affect doctor-patient communication in ward round settings? "How should mobile point-of-care systems be designed to support the doctor-patient dialogue?" "How should usability evaluations with multiple users be planned and conducted to maximize the value and validity of the results"

Paper 8: Card Ranking

Authors:	Ole Andreas Alsos and Yngve Dahl
Full title:	Ranking for Reflection: The Application and Added Value of Picture Cards in Comparative Usability Testing
Published in:	Presented at Yggdrasil 2008, available at [http://bit.ly/paper8]
Authors' contributions:	Alsos and Dahl wrote the paper.
What was already known on the topic:	Comparative usability evaluations and preference rankings are useful in terms of informing further system design. For test participants such evaluations can be challenging since they must remember and distinguish between different design solutions.
What this study added to our knowledge:	Ranking exercises with picture cards illustrating design solutions is a non-intrusive, cheap, and efficient technique that are highly useful in the context of comparative usability testing. In addition to providing quantitative data on users' preferences, the technique helps users distinguish between design solutions, promotes user reflection, aids the test subjects' memory and act as a concrete and common reference tool for both test subjects and facilitator during post-test interviews. It also simplifies the post-test data analysis.
Relation to research questions:	"How should usability evaluations with multiple users be planned and conducted to maximize the value and validity of the results"

7.2. Relation between papers and research questions

Table IX gives a summary of how each paper contributes to the research questions. In addition, the relations between the papers are presented in Figure 28. It is important to note that *Paper 8* does not contain a significant scientific contribution, but is included for completeness and to elaborate on methodological issues.

Table IX. The relation between research papers and research questions.

	Research papers							
Research questions	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
(1) Effects of mobile systems on doctor-patient communication				•	•	•	•	
(2) Designing guidelines for mobile point-of-care systems				•	•	•	•	
(3) Methods for lab-based usability evaluations	•	•	•				•	•

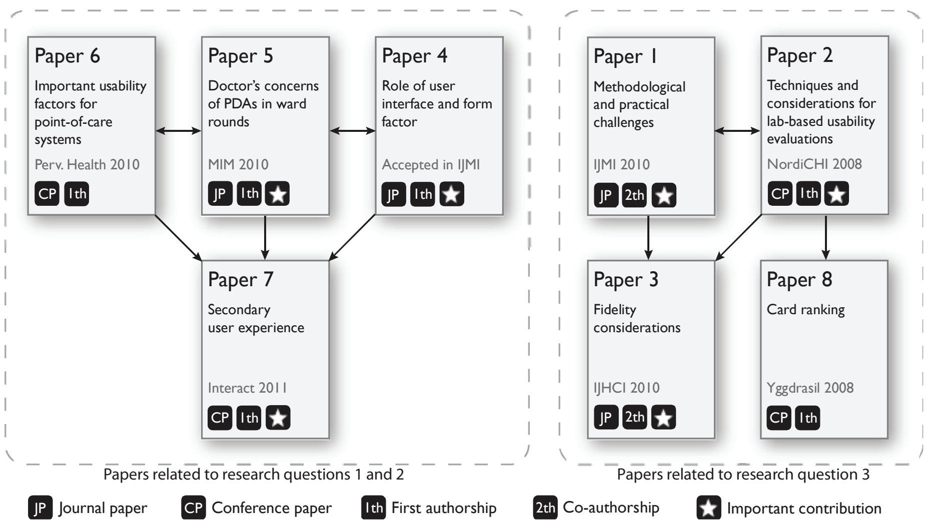

Figure 28. Relations between papers. An arrow from one paper towards another indicates that the latter is a result of the former.

7.3. Conclusions

This chapter has presented an overview of the papers, the main contributions, and the authors' contributions. As independent papers, each of them has provided a significant contribution the body of knowledge. The next chapter will synthesize and discuss the research contributions and combined implications of the papers.

8. Discussion and Implications

In the previous chapter the results of the research papers were summarized. In this chapter the main contributions of this thesis are synthesized. These contributions are:

(1) Effects of mobile point-of-care systems on doctor-patient communication.
(2) Guidelines for designing mobile point-of-care systems that support doctor-patient communication.
(3) Methods to maximize value and validity of usability evaluations with doctors and patients.

While the first contribution discusses the *effects,* the second contribution should be viewed as the *design implications* drawn from the first (Figure 29). Further the third contribution should be viewed as the *methodological implications* of the lab-based usability evaluations that were conducted.

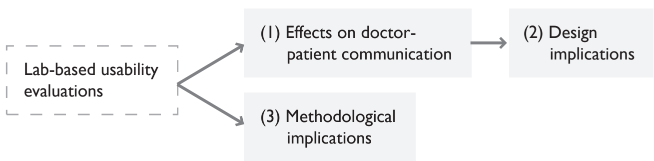

Figure 29. The thesis has three related contributions.

The implication and relevance of these contributions for researchers, practitioners and users are also discussed.

8.1. Observed effects of mobile point-of-care systems on doctor-patient communication

As presented in Chapter 3, there are a number of benefits of using mobile systems in ward rounds; the clinicians get updated and timely information at the point-of-care, which are important elements in the treatment and care of the patient. However, as presented in Chapter 2, there is little knowledge on what effects the use of mobile point-of-care systems in ward round consultations have on the communication between doctors and patients. As part of this thesis work I have observed five effects of mobile systems on doctor-patient communication; that (1) face-to-face and (2) non-verbal communication is affected, (3) that the visibility of physicians' actions are reduced, (4) that communication practices change, and (5) that spoken language is influenced. These findings are presented and discussed below.

Reduced face-to-face communication

As presented in Section 2.1, gaze and eye contact are important components of communication. However, in *Paper 4* and *Paper 5* it was found that the shape and affordances of some mobile solutions (i.e. the laptop on wheels) made it awkward for physicians to position themselves near the patients. This made it more difficult to align and realign eye contact with the patient (Figure 30, *right*). Sometimes this also hindered conversation openings (verbal communication were not measured). This is what McGrath et al. (2007) refer to as *closed* or *blocked use*. On the other hand, when physicians used the paper chart or the handheld devices, this problem was neither observed nor reported. The use of the paper chart and the small mobile devices allowed the physician to face the patient regardless of room layout (Figure 30, *left* and *center)*

The closed or blocked use can have some negative consequences on doctor-patient communication. First of all, drawing from the literature on gaze (Argyle and Cook, 1976), lack of eye contact can make doctors appear less attentive and less interested in the patient. This can impair patient satisfaction. Further, increasing distance to the patient makes it even more important to have eye contact.

Second, the use of such devices reduces attentiveness of the patients and can make it harder for the physician to interpret their actions and body language. It can also lead to turn-taking breakdowns, as observed in *Study 3 (Paper 4)*. In addition, psychosocial problems may be overlooked by the physician, something that has been previously reported with the use of stationary computers in primary care by Margalit et al., (2006). This can potentially have serious consequences for the patients' health.

Overall, the findings show that some mobile point-of-care systems make *face-to-face* communication more difficult. This can reduce eye-contact, make physicians appear less attentive, obstruct conversation openings and cause turn-taking breakdowns.

Figure 30. With the paper chart (*left*) and the PDA (*center*) the physician is always facing the patient while looking for information, making it easy to re-establish eye contact with the patient after use. When using the laptop on wheels (*right*), the physician is faced away from the patient. This makes it harder to re-establish eye contact after use (Figure from *Paper 4*).

Impaired non-verbal communication

In *Paper 4* and *Paper 5* it was shown how physicians used the paper chart to invite patients to speak by tilting the paper chart towards them (Figure 31, *top left*), and to indicate that the ward round was ending by closing the chart (Figure 31, *bottom left*). This was not seen with the mobile devices (Figure 31, *top* and *bottom right*).

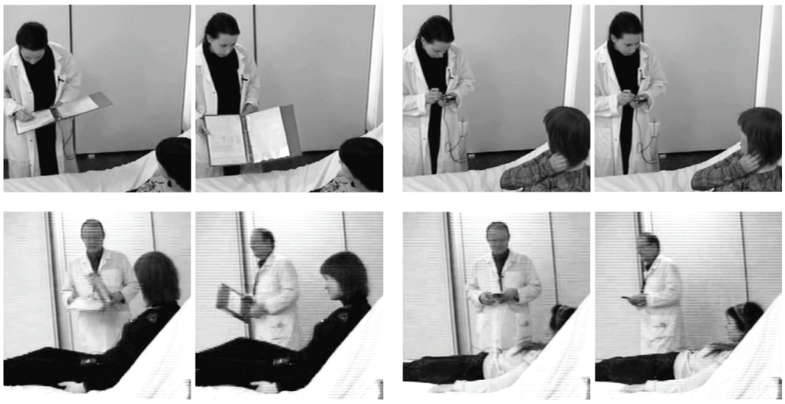

Figure 31. The physicians invited patients to speak by tilting the chart slightly towards them (*top left*). This was not found for PDA usage (*top right*). Moreover, they signaled that the ward round was ending by closing the paper chart (*bottom left*) and placing the pen back in the chest pocket. This was not possible with the PDA (*bottom right*). (Figure from *Paper 4*).

The interpretation of these findings is that physicians communicate non-verbally with the patient. The first example is what Kendon and Ferber (1973) describe as a topic opening, while the last example is what Knapp et al. (1973) call a conversation closing. The paper chart is used as an object in non-verbal behavior to start a new topic or close the conversation. This non-verbal behavior was not seen with the mobile system. One interpretation, drawing on awareness and affordance literature, is that the device to a little extend affords this behavior. It does not have the form factor to configure awareness or to produce add-on awareness. Another interpretation is that the mobile devices are new for the physician, and that the use of the device in non-verbal communication needs to be developed with time and training.

Although this is a clear effect on the non-verbal aspects of doctor-patient communication, the relevance for patient outcomes is limited. The physician will most probably compensate with other types of behavior, such as explaining usage or by using other kinds of gestures.

Reduced visibility of actions

As presented in Chapter 2, so that turn taking in conversations can flow smoothly, implicit signals, such as body language, gaze and tone of voice are used to take or give up 'the floor' (Sacks, et al., 1974). In *Paper 4* it was argued that the visibility of actions on the information device is one such implicit signal; the patient knows when not to disturb the physician and colleagues know that they can overtake the conversation with the patient when they see that the physician is busy.

In *Paper 5* it was shown how the physicians' actions performed on the mobile devices, from the patients' perspective, was less distinct, visible and transparent compared to actions performed on the paper chart (Figure 32 and Figure 33). In *Paper 4* it was argued that the physicians produced awareness as a by-product (cf. Section 2.7) that could be used by the patients to understand the physicians' actions.

Figure 32. Adding (*left*), obtaining (*middle*) or searching for information (*right*) with the paper chart. Actions are highly distinct and visible for the patient.

Figure 33. Adding (*left*), obtaining (*middle*) and searching for information (*right*) with the PDA. For the patient the actions appear nearly identical.

Gutwin and Greenberg (2002) found that interaction can be anticipated when actions are visible. When the paper chart is used, large, distinct and highly visible gestures are produced. In contrast, actions on the mobile device, such as keyboard typing, mouse clicking and screen tapping, are smaller, ambiguous and less visible for the patient. First of all, this can make it harder for the patient to anticipate what the physicians do. Second, it can lead the patient to believe that the physician is doing something else than he/she does. The effect may be more frequent turn-taking breakdowns and a negative effect on doctor-patient communication.

Changing communication practices

In *Paper 5* it was demonstrated that the physicians used paper and mobile devices differently; they tended to surf around more and rely more on the information, functions and possibilities offered by the mobile device (Figure 34). In addition, the patients responded negatively to the communicative aspects of mobile usage. They felt less encouraged to interact with the physician and feared they would disturb him/her with questions.

Although not backed up with time analyses, the qualitative findings demonstrated a shift towards more interaction with the *virtual patient* through the mobile device and less interaction with the *real patient*. From the physician's point of view, the virtual patient provides the physician with reliable, accurate and detailed information that can give them necessary background information. This will increase the quality of medical decisions that are taken.

However, from the patient's point of view, the quality of the dialogue with the physician worsens because of the shift of attention towards the mobile device. For example, as presented above, patients felt that they could not disturb the physicians because they appeared to be busy. As shown in Chapter 2, this may have negative consequences for the assessment of the patient's health. This shows that physicians are faced with a trade-off between seeking information from the information device and attending to the patient.

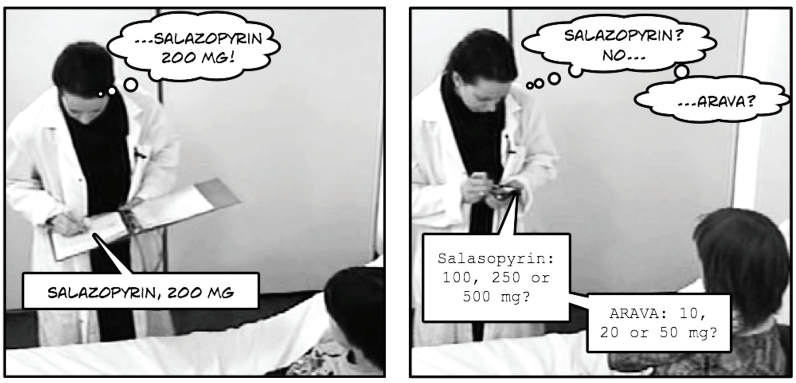

Figure 34. The physicians tended to surf around more on the mobile device and rely more on the functions and possibilities offered (Figure from *Paper 5*)

Another finding, presented in *Paper 4*, was that the effect of mobile systems on communication is highly dependent on the individual characteristics of the physician. Some physicians were very successful in their communication with their patients despite sharing their attention with them and the mobile device. For other physicians, the use of a mobile device had serious negative impact on their communication with the patients.

However, as touched upon in *Paper 5* and discussed in more detail in *Paper 4*, the negative effects of using mobile devices on doctor-patient communication may be reduced with time and training. First of all, physicians can learn how to use the mobile devices with a minimum of impact on patient health outcomes. Second, the patients' reactions to the use of mobile technology in consultations will probably adapt to changing norms.

Spoken language is influenced

In *Study 3 (Paper 7)* a pause symbol, **II** , as used in music and video players, was used on a button in the GUI. The button allowed the physicians to temporarily cease medical treatment without removing it from the medication list. The physicians started to use words like "pausing this drug" rather than term "temporary cessation of medication", which was commonly used when the same physicians used the paper chart in the control study. This further supports findings from *Study 1* (Alsos, 2005), where the underlying design metaphor used in the mobile systems influenced the language used by the physicians.

As Ong et al. (1995) point out, most patients are unfamiliar with medical language and terms. While "pausing" is obvious for the patients, the term "temporary cessation" is a foreign word for most of them. Drawing on the literature review presented in Chapter 2, the use of medical language in consultations can lead to communication problems, reduce the patients' understanding of information, and undermine the foundation for shared decision making. This in turn can have negative impact on patient outcomes.

The findings reveal two important effects on doctor-patient communication. First of all, they demonstrate that the *language used in the user interface* can have an impact on communication. It appears as the terms used in the user interface guides, or even tricks, the physician to use the same terms. Second, the findings show that the use of everyday language in the prototypes (*Study 3*) influence the language spoken by the physicians compared to the paper chart.

Summary

Table II in Chapter 2 presented an overview of the current body of knowledge on doctor-patient communication and how stationary and mobile computers affect this communication. In Table X below, which is a copy of Table II except for the last column, it is shown where this thesis has provided a contribution. The findings have not provided all the answers, and there are still holes to be filled. There is still a lot to be discovered in each cell.

Table X. Right-hand column shows new contributions on how mobile computers affect best practice in patient consultations.

Characteristics of doctor-patient communication	**Best practice in patient consultations**	**Reality with computers in primary care**	**Reality with mobile computers**
Information exchange	Patient allowed to provide information uninterrupted, physician provides enough information	Less medical dialogue, but more information exchange and better explanations	**Usability problems impair the clinical dialogue**
Shared decision making	Decisions are made by agreement of both physician and patient	Computers can enhance shared decision making	(No data)
Trust	Trust is established between physician and patient	(No data)	**Physicians using handhelds are trusted less**
Technical competence and efficiency	Physician displays efficiency and high technical competence	Good computer skills means better commu-nication with patient	**User problems affect communication with patient**
Use of language	Physician use everyday language	(No data)	**Spoken language is influenced**
Practice of non-verbal behavior and eye contact	Physician uses non-verbal behavior, such as touch and eye contact	Computer use may reduce non-verbal behavior and eye-contact	**Mobile devices are not designed to support non-verbal communication**
Physical room layout	Room layout supports communication	Spatial configuration of computer can disturb communication	**Small devices support communication with any room layout**
Time spent reviewing patient charts	Physician reduces time reviewing patient charts	Physicians will spend more time on the computer and less time on the patient	**Physicians tend to surf around more on a mobile device**
Instrumental and affective utterances	Physician uses both task focused and socioemotional utterances	(No data)	**Mobile devices lead to less non-verbal communication**

8.2. Guidelines for designing mobile point-of-care systems that support doctor-patient communication

While the previous section concerned the *effects* of mobile point-of-care systems on doctor-patient communication, this section presents empirically or theoretically grounded design implications and guidelines for *designing* such systems. The main findings are (1) that the patient should be viewed as a secondary user with secondary user experience, (2) that doctor-patient communication should be acknowledged as an important usability criteria, (3) that the graphical user interface and (4) the device form factor design can be designed to support the communication.

Designing for the secondary user experience

Chapter 3 presented how the customers in client-customer relations can be viewed as secondary users. In *Paper 7* it was found that the patient shares the same characteristics as secondary users:

- The patients interacted with the physician, who interacted with the system.
- The patients did not interact with the system themselves (except from in study 1)
- The patients relied on the physician to get information, such as names of drugs, dosages, and side effects.
- As discussed in the previous section, the patients were influenced by the physicians' use of the system.

Also, In *Paper 5,* it was revealed that patients had strong opinions about the handheld medication system, even though they had neither used nor seen the graphical user interface. In addition, *Paper 7* presented a number of empirical findings showing that patients have an experience of the physicians' use of the mobile point-of-care system.

Together, this suggests that *the patient is a secondary user* of the point-of-care information system. This also implies that the patient has a user experience, or to be more specific, a *secondary user experience*. As no existing definitions of the user experience of secondary users have been found, it was defined as follows in *Paper 7*:

> The secondary user experience of a system is the part of the overall experience of the secondary user that can be attributed to (1) the primary user's interaction with the system, or (2) the secondary user's interaction with the system with the primary user as an intermediary.

Secondary user experience relates only to the experiences of the secondary user, in contrast to *user experience*, which relates only to the primary user, and *co-experience*, which relates to the social interaction between both primary and secondary users in the presence of a system (see Figure 35).

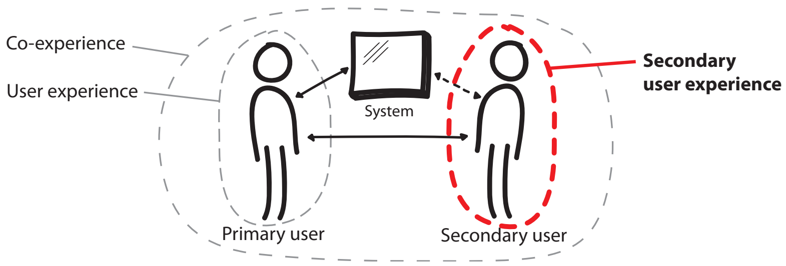

Figure 35. User experience relates to the primary user, Co-experience relates to the shared experience of the system of both users, and secondary user experience relates to the secondary user. The solid arrows indicate interaction, while the broken arrow indicates indirect interaction (Figure from *Paper 7*).

Regarding the patient as a secondary user with a secondary user experience may be a guiding framework for designing mobile point-of-care systems that support doctor-patient communication:

Secondary user experience is relevant for patients. The positive correlation between patient satisfaction on health outcome was established in Chapter 2. When patients report that they are satisfied or dissatisfied due to the physician's interaction with the system, i.e. their experiences as a secondary user, it can be assumed that it has some impact on the overall patient satisfaction. Therefore, it is suggested that the perspectives of the secondary user are included throughout the design process. In addition, it is suggested that usability evaluations need to include both the primary and secondary users together and that also the patients need to be asked about design issues.

Trade-off between primary and secondary user experience. As shown in *Paper 7*, when the user experience was improved for the physicians, in some it could cases have negative effects for the patients, as the doctors' ability to hide information on the mobile device improved. In addition, it was found that when the secondary user experience was improved, it sometimes created new problems for the physicians, e.g. reducing the ergonomics when interacting with the system. Consequently, aspects of the user experience for the primary user can have negative consequences for the secondary user. In a similar manner, improving the user experience for the secondary user can have negative consequences for the primary user. The trade-offs need to be addressed by designing the primary and secondary user experience together. Designing the primary user experience before the secondary, or vice versa, could lead to a suboptimal solution for one of the parties.

Doctor-patient dialogue as an important quality criterion

Viewing the patient as a secondary user has some important implications for what we consider is an important quality criteria for mobile point-of-care systems.

Usability goes beyond the graphical user interface. As presented in *Paper 1,* the usability of mobile EPR systems is to a large extent determined by factors that go beyond that of the graphical user interface. Since the context of use, as defined in Chapter 3, can be complex in a hospital setting, this makes usability of mobile EPR systems a multi-faceted concept, with several influencing factors. These factors include ergonomic aspects such as the ability to have both hands free, social aspects such as to what extent the system disturbs the face-to-face interaction between the health worker and the patient, and factors related to how well the system integrates with existing work practice (Figure 36).

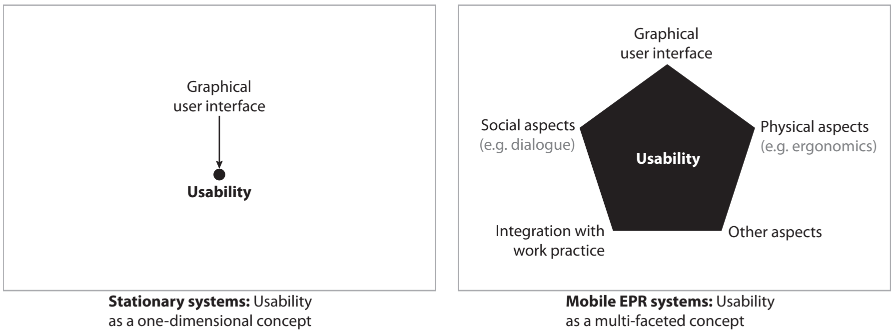

Figure 36. In contrast to stationary systems, the usability of mobile EPR systems not only is dependent of the graphical user interface, but can be viewed as a multi-faceted concept. Also social and physical aspects are important for the overall system usability.

Doctor-patient communication is an important quality criterion. In the same way as the four C's (clarity, carat, color and cut) are important quality criteria for diamonds, a number of quality criteria for mobile point-of-care systems can be formulated. In Table IV and Figure 13 in Section 3.4, a list of criteria that the literature has found to be important for the overall quality of the health care system was summarized. In Section 8.1 a number of observed effects of mobile point-of-care systems on doctor patient communication was presented. Based on these effects, which can have both positive and negative consequences on patient outcomes, it is suggested that the ability for the system to support the dialogue between doctors and patients has become an important quality criterion (Figure 37).

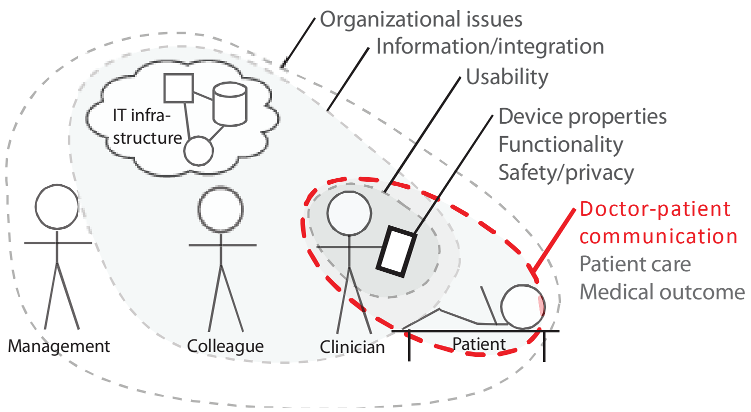

Figure 37. Usability criteria for mobile point-of-care systems and how they relate to different actors in the hospital. Doctor-patient communication is an important usability criterion for the doctor and the patient.

Designers and developers need to broaden their scope. It is well established that doctor-patient communication is critical for the successful diagnosis and treatment of medical problems (see Chapter 2). However, as presented in Section 3.4, new mobile point-of-care systems seem to focus entirely on the needs of the physicians. The focus is on measurable properties, such as battery lifetime, mobility, functionality, or information overview, rather than on the ability of physicians to communicate and collaborate effectively with the patient. Both the systems manufactured and the evaluation studies undertaken, have a very limited scope of who the user is.

Clinicians may leave the technology at the doorstep of the room where the patient is if it impedes the doctor-patient communication. Therefore, designers and developers of mobile EPR systems need to broaden their scope and look outside the traditional requirements for collaborative systems (Figure 38). In addition to accommodate the users' basic information need, the systems should support the critical dialogue with the patient.

One way to do it is to also view the patient as a user. Not as a primary user of the system, but as a *secondary user*, who does not use the system directly but instead uses the physician's actions and interactions with the system to become aware of the course of the ward round. This new success criterion has to become a testable usability requirement, and should be assessed before approving it for hospital use.

Figure 38. The designers and developers of mobile point-of-care systems need to broaden their scope about who the user is.

However, how this new usability requirement can be evaluated requires further work. One possibility is to use objective measures, such as eye-contact time or different interaction analysis systems (cf. Section 5.2). Another approach is to use subjective measures, which can involve interviewing both primary users and secondary users. In addition, questions related to the doctor-patient dialogue can be added into questionnaires that measure the usability of systems, such as the *System Usability Scale* (Jordan, 1996).

Factors relevant for doctor patent communication. In Chapter 2, a list of quality criteria based on current knowledge of mobile health care systems was assembled. In *Paper 6*, it was found that there are a number of factors that affect the overall perceived usability and user acceptance of mobile point-of-care systems (Figure 39). Together with the findings from *Paper 5* and *Paper 4*, many of these factors are relevant for the doctor-patient communication. Figure 39 incorporates the most important factors into an illustration. Designers and developers should have these factors in mind when designing mobile point-of-care systems.

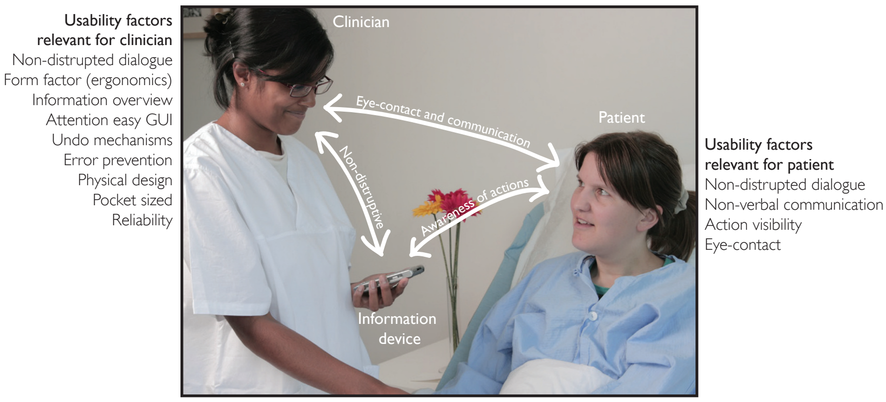

Figure 39. A number of factors are relevant for doctor-patient communication. Designers and developers should have these factors in mind when designing mobile point-of-care systems.

Designing the user interface to support the doctor-patient dialogue

In *Paper 4* and *Paper 5* it is presented how the design of the user interface influence the communication between doctors and their patient. Given that designers and developers of mobile point-of-care systems acknowledge doctor-patient communication as an important quality criterion, there are some measures that can be taken to improve the user interface.

Design user interfaces that require little attention. As presented in Section 3.2, people have limited cognitive resources and cannot attend to many things at the same time. Furthermore, as the current findings demonstrate, the use of the point-of-care system draws the physician's attention away from the communication with the patient.

The following example from *Study 3* illustrates this: The medication system used was deliberately made as simple and user-friendly as possible by reducing the functionality and by basing the user interface design on principles that reduce the users' cognitive load. The physicians' comments on how easy it was to operate verified that the system was simple and user-friendly. However, when they tested the system in a ward round situation and in the presence of a patient actor, we observed that even this simple system drew their attention away from the patient and the dialogue. In accordance with this, the patient actors reported poorer dialogue with the physician when a PDA was used. A fully developed system must have a much wider set of features and therefore more complex GUI or navigation structure. Extrapolating the findings of this study, it is concluded that the problem of distraction is of critical concern in the design of small-screen user interfaces for healthcare information systems.

Designers and system developers of mobile point-of-care systems need to design user interfaces that require as little of the user's attention as possible. This will allow physicians to use most of their attention on the patient rather than the system. Examples from other domains show that it is possible to make mobile user interfaces that allow the user to focus their attention on others while using the system (Pascoe et al., 2000).

Provide system feedback. Given the poor action visibility provided by mobile systems, together with the new view of patients as secondary users, the system feedback should be visible to all participants in the ward round. As reported in *Paper 5,* the patients, as secondary users, get very little feedback from the system. As also suggested by Luff et al. (1992), sounds or lights can reflect the physicians' interaction with the handheld system. For example, different sounds might reflect different interactions, such as reading, adding or navigating. However, sounds and lights can be both intrusive and disturbing for all the actors in ward round. It is therefore important that such effects are wisely designed. A sound does not need to be produced by the loudspeaker of the device – the subtle click of pushing a physical button can be sufficient.

Provide a GUI and/or display tailored for the patient. In *Study 1* (Alsos and Svanæs, 2006) it was found that when displaying information adapted for the physician on a mobile device, and for the patient on a patient terminal, the user experiences of both were improved. When displaying the information adapted for the physician on both devices, the patient's user experience was reduced. Therefore, if it is feasible and necessary, an additional display/GUI with information tailored for the secondary user should be provided. This will give the secondary user a version of the information where unnecessary complexity and irrelevant information is removed.

Simplify the process. As discussed in *Paper 5,* general input, and free text input in particular, on mobile devices is often difficult, time consuming and cognitively demanding in the mobile use context of a hospital. To prevent negative effects on doctor-patient communication input should either be kept to a minimum, or made as simple as possible.

One solution that can reduce the physicians' cognitive load when using handhelds at the bedside, is to design mobile systems that are fine-tuned to effectively support the fastest and easiest tasks. At the same time they should allow partial completion of the more complex tasks. Then the physician can complete the quick and easy tasks at the point-of-care, while the more complex tasks can be started at the bedside and completed in the office. This will prevent the physicians from getting absorbed in endless forms and lengthy drop-down lists at the point-of-care when they should be involved in a dialogue with the patient.

Interaction technique considerations. The interaction technique is an essential part of the interaction with the system. An awkward interaction technique may demand much of the physicians' attention. This will reduce their ability to attend the patient and may reduce the quality of the doctor patient dialogue, as discussed in in *Paper 6*.

The comparison of the different interaction techniques in *Paper 6* reveals that physicians have strong opinions about the techniques they use, and that these opinions vary widely between individuals. Given the large variation in users' preferences it may seem at first thought advisable to provide the system with multiple interaction techniques and leave the final choice to the user to accommodate their individual needs. However, this requires that the user interface is tailored to accommodate all the interaction techniques, which may require suboptimal and costly solutions.

In the comparison of interaction techniques for use in ward round situations, it was found that the input technique must:

1. Allow for flexible usage.
2. Have good mapping between input and output controls.
3. Should not be dependent on an additional tool such as a stylus or pen.
4. Should be accurate and precise.

5. Should allow for one-handed usage.
6. Should give tactile feedback.

For example, the button and keyboard-based interaction techniques give good tactile feedback, but are slower and has poor mapping between the controls and the screen. Stylus-based interaction gives good precision, but the stylus/pen tend to get lost. The paper chart fulfills almost all the above-mentioned recommendations, but it cannot be operated one-handed and is dependent on the pen.

Some of the emerged issues with the different interaction techniques could be attributed to lack of experience with PDAs and the medication system, and are expected to vanish with increasing usage experience. Moreover, new technologies, such as touch screens with better precision and tactile feedback (Hoggan et al., 2008), together with increased acceptance and popularity, will make the views on mobile devices and appropriate interaction techniques evolve quickly.

The use of language in the user interface. As presented *Paper 7* and in Section 8.1 above, the written language implemented in the user interface affects the oral language used by the physician. This suggests that in order to guide the physicians to use everyday language in patient consultations, the language of the mobile EPR systems should be carefully designed to use everyday terms and symbols rather than medical terms. By presenting the information for the primary user in the language of the secondary user, the primary user can be guided to use simpler terms and communicate on the same level as them, i.e. physicians use terms like "pause" instead of "temporary cessation". This can make it easier for the patient to understand the topics discussed in the consultation and can prevent misunderstandings. This in turn can improve the secondary user experience. However, this will have consequences for the primary user, because the everyday language is not as precise as medical language.

Designing the device form factor to support doctor-patient communication

As presented in Section 8.1, the mobile point-of-care system has a negative effect on action visibility, communication, and patient satisfaction. Drawing on *Paper 4* and *Paper 5,* it is suggested that improvements in the device form factor can prevent some of these negative effect by (1) increasing the action visibility, (2) supporting gesturing and non-verbal communication, (3) making the device pocket sized, and (4) making the device design more neutral than a personal device.

Increasing the visibility of actions. To make the patients more aware of what the physician is doing, and provide alternative system feedback to them as secondary users, several changes in the form factor can be made. One solution is to provide system feedback, as presented above.

Another solution that can increase the action visibility is to design mobile devices with semi-transparent screens where blurred content is visible by the patient from the back of the screen (Figure 40). This will make it possible for the patient to get an idea of what the physician is doing or looking at; not enough to read or see details, but enough for the patient to be aware of the physician's actions and to distinguish between free text notes, tables (typically medication lists or lab results) or x-ray images. Even if it will be possible to differentiate between text, images and different screens, it will be impossible to read, thus being completely anonymized.

Figure 40. A mobile device with semi-transparent screen can make physician's actions more visible for patients (photomontage).

Support gesturing and non-verbal communication. The quality of the non-verbal aspects in face-to-face communication has a strong impact on the secondary user experience (*Paper 7*). The findings indicate that a system can hinder this communication, especially with a system that occupies the hands or hides the face of the primary user. Therefore, the physical form factor of the system needs to support non-verbal communication. It is suggested that this can be solved with an improved form factor design that affords gesturing and non-verbal communication. For example, by providing a handheld device with a cover, the physician can inform the patient that the visit is going to end by closing it. In addition, thinner and lighter devices can make it easier for physicians to use it to produce add-on awareness as the gesture become more obvious. Augmented or digital paper may provide such affordances.

Make the device pocket sized. As reported in *Paper 5*, patients preferred that the information device did not occupy space between them and the physician. In addition, some physicians conducted physical examinations of the patient. In such situations, the device got in their way, and several physicians solved this by placing it in the pocket (Figure 41). A pocket-sized device will allow the physicians to stow it away in their lab coat pocket when not using it, or when they need both hands free for patient examinations. This can enable them to direct their full attention towards the patient. As a positive side effect, the patient will be clearly aware of when the physician is in the listening or input mode. The direct consequence of this design guideline is either to shrink the mobile device to the size of the lab coat pocket, or manufacture lab coats with larger pockets.

Figure 41. A pocket-sized device will allow the physicians to stow it away in their lab coat pocket (arrow) when not using it, or when they need both hands free for patient examinations.

Use a neutral device design. In Paper 5, it was found that patients regard the mobile point-of-care system as a mystical thing (*Study 1*), and that doctors were worried that the device might look like their private device (*Paper 5*). To make the patient confident that the device is not the physician's personal tool, care should be taken to give the device a neutral design, or better, to make it look like hospital equipment.

8.3. Methods to maximize value and validity of usability evaluations with doctors and patients.

As discussed upon in the previous section, designers and developers need to include secondary users (i.e. patients) in the evaluations of the mobile systems. This means that usability evaluations are conducted as "in-sitro" evaluations (Kjeldskov and Skov, 2007), where one attempts to recreate the context of use in the lab setting. Furthermore, this has some implications on how the evaluations are conducted to maximize the value and validity of the results.

In Chapter 4, a number of research challenges related to usability evaluations of health information systems were presented. In addition to these findings, four significant contributions on evaluation methodology have been established. These are (1) unobtrusive, multi-perspective recording techniques, (2) how to encourage and capture user reflection,

(3) the added value of card ranking exercises, and (4) how to ensure just enough simulation fidelity.

Unobtrusive, multi-perspective recording techniques

As presented in Chapter 4, current recording techniques in usability evaluations are often intrusive. In *Paper 2*, it was found that non-intrusive recording techniques from multiple perspectives can provide a more valid and precise understanding of physical and ergonomic aspects of mobile designs. The perspectives should as a minimum include recordings of the participants' interaction with (1) the graphical user interface, (2) the physical device, and (3) the environment, i.e. patient, tools, beds (Figure 42). With the use of remotely controlled dome cameras in combination with mirroring software on the device, the researcher avoids the problems with user- or device-worn recording devices. In addition, the researcher can make the moderator-controlled recordings practically invisible for the participants, thus increasing the ecological validity of the studies.

The drawback is that the researcher constantly has to monitor the study, and has to zoom in and follow the user's interaction with the physical device. This can be challenging when the user moves between rooms or moves into blind spots of the camera. In addition, the approach may require several remotely controlled cameras if the area to be covered is large. The approach is therefore not feasible for evaluations in the field.

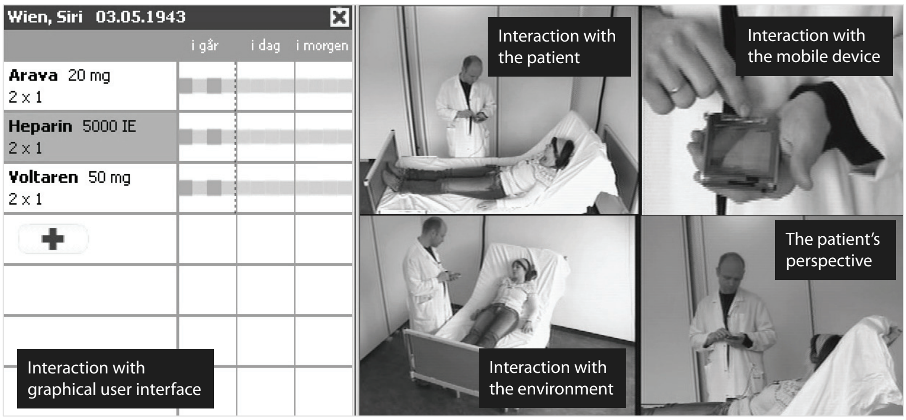

Figure 42. The figure represents a frame from a lab-based usability evaluation. One key finding was that non-intrusive recordings from multiple perspectives are important to provide a precise understanding of what happens in the evaluations.

Encouraging and capturing user reflection

In Chapter 4 the challenges with encouraging and capturing the participants' reflections during usability evaluations were highlighted. This was also discussed in *Paper 2,* which described techniques about how the participants can be encouraged to reflect on design solutions and how the researcher can capture these reflections.

Think aloud works poorly. It was found that in certain evaluation setups, the traditional techniques, such as think-aloud to capture user reflections, work poorly when tasks or scenarios require participants to interact or communicate with other actors (such as patients) that play a role in the scenario, as they tended to maintain the dialogue with these actors, not the moderator.

Multiple test participants encourage user reflection. It was found that evaluating the design solutions with multiple test participants (group usability evaluation) could encourage user reflection and make the participant's reflections easier to capture for the researcher. For example, the test participants in some cases made the other participant aware of what they are doing by talking aloud or showing their actions. In addition they discussed the solutions between them afterwards.

Multiple design alternatives encourage user reflection. It was easier for the participants to comment on a solution when they were able to compare it with other solutions. This suggests that by presenting the participants with a more extensive part of the design solution space, their awareness to design issues that is not immediately recognized when using a solution first-time is increased. This allows participants to compare the characteristics of one solution to the characteristics of others, and enables them to give a more comprehensive rationale for their preferences.

Short on-site interviews can replace think aloud. When evaluating multiple design alternatives this research found that *short on-site interviews* immediately after a participant had used a design solution was a good alterative to think-aloud (which worked poorly when multiple actors were involved in the evaluations).

Prototypes available during interviews encourage user reflection. By making prototypes and devices available during the interviews, it was easier for the participants to recall, reflect and discuss the design solutions they had tried (Figure 43).

Figure 43. Figure *a* shows how short on-site interviews with multiple test participants were performed between evaluating the different design solutions. Figure *b* shows how prototypes, in this case a paper chart and a mobile device together with picture cards representing them, were available during the post-test interview (highlighted with arrows).

The added value of card ranking exercises

Paper 2 and *Paper 6* described a card ranking method that was used in three of the four experiments that this thesis is based on. This method is further described in *Paper 8*. The method has been particularly useful in comparative usability evaluations, as the points below describe:

- Card ranking encourages user reflection by provoking second thoughts, re-evaluations, and offering the possibility for test participants to compare strengths and weaknesses of the various solutions.
- The cards support the test participants' memory by providing a concrete reference tools that help them remember and distinguish between various design solutions.
- The cards facilitate post-test interviews by focusing and guiding the discussion, by reducing confusion, and by being a common reference between the facilitator and the test participant.
- It makes data analysis easier since the researcher can see and interpret what designs and design aspects the participants refer to during the interview.
- Card ranking provides quantitative data on users' preference, which can be used as a statistical indicator for which designs and design aspects that are most preferred by the users and therefore appropriate for further development.
- The technique is cheap, unobtrusive and efficient, and is particularly useful in the context of comparative usability evaluations.

Given the arguments above, the technique can facilitate the important post-test interview and gets the most out of each test participant. The technique can increase the value of usability evaluations of health information systems. The drawback with the method is that to get significant statistical values of the rankings, many test participants are required. This conflicts with best practice of usability evaluations, which suggests evaluations with few participants followed by a redesign and another evaluation, rather than one large evaluation with many test participants.

One surprising finding was that the card ranking method worked well when the doctor and the patient collaborated on this exercise (Figure 44). It evoked reflection and generated discussion, but most important it illuminated issues from the perspective of both parties. (It was one of these card ranking exercises that first made me aware of the secondary user experience)

Figure 44. After testing a number of design solutions (*left*), the users were asked to comment on each solution and sort corresponding picture cards in preferred order (*middle*). The final sort order represented the users' preferences (*right*). (Figure from *Paper 8*).

"Just enough" simulation fidelity

In *Paper 1* it was found that to be able to measure the usability factors that go beyond what can be found by a traditional stationary user interface evaluation, it is necessary to conduct usability tests of mobile EPR systems in physical environments that simulate the conditions of the work situation at a *high level of realism*.

In addition, the use scenarios must be realistic. This often means that *the tests must be run as role-plays with multiple stakeholders* as participants, e.g. physicians, nurses, and patients. For example, the responses of the physicians are much more realistic when there is a patient in the bed. In addition it means that both the scenarios and the environment need to be developed in close cooperation with domain experts.

However, as described in *Paper 2* and *Paper 3*, for optimal cost-benefit the physical environment, prototypes, and scenarios should be designed with *just enough realism* related to the research questions asked. This means finding the right simulation fidelity so that the participants accept the simulation as the real world without replicating it completely.

Simulation fidelity plays an important role in whether the participants accept the simulation as a credible replacement of the real world. One important contribution is the simulation acceptance model, which shows the factors that influence the extent to which a simulation experience evokes commitment and engagement among participants (Figure 45). The function f is a threshold, showing that each fidelity component needs to have a minimum of realism in order to be accepted by the participants. All four fidelity components need to be accepted in order to make the participant accept the simulation, $\prod(f)$. In other words: if one fidelity component fails, the simulation will not likely be accepted. Together with external factors, such as personal attitudes, interests and incentives, simulation acceptance is an important factor for commitment and engagement. The simulation acceptance model is further described in *Paper 3*.

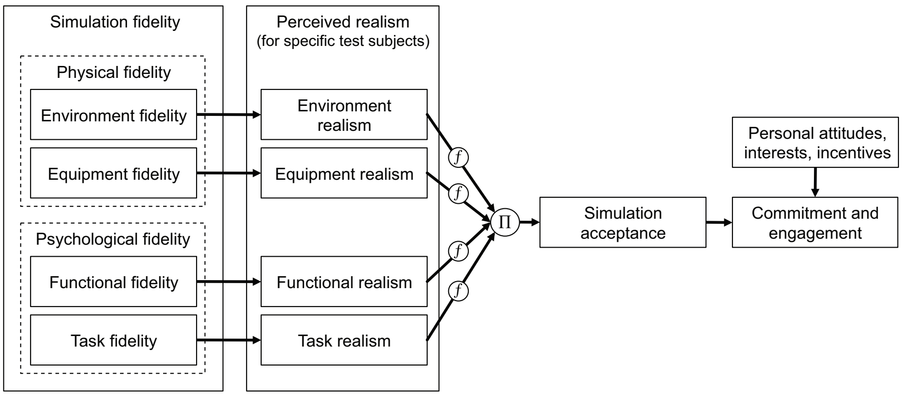

Figure 45. The Simulation Acceptance Model shows that a number of fidelity components are important for the user's acceptance of the simulation. Each component needs to have a minimum level of fidelity in order to be accepted, and all components need to be accepted in order to evoke commitment and engagement (Figure from *Paper 4*).

8.4. Implications and relevance

As presented in Section 5.3, *relevance* is about whether the phenomenon actually happens in the real world and whether the findings are potentially useful and applicable for solving real-life problems. The research contributions presented above have potential implications and relevance for researchers within the fields of *Health Informatics*, *Medicine*, *Human Computer Interaction* and *Computer Supported Collaborative Work*. Further, the contributions can have relevance for the software industry, or to be more precise, *designers* and *developers* of EPR systems and mobile point-of-care systems. In addition the findings may have relevance for users, i.e. *clinicians* and their *patients*.

Implications and relevance for researchers

The contributions may have relevance for researchers in the fields of:

- *Health Informatics* (HI), which may benefit from contributions on design guidelines and usability evaluations. The latter can be incorporated into recommendations for health technology assessments (cf. Section 4.1) of EPR systems.
- *Medicine* (Med), as the contributions have provided new insights about how mobile devices affects the communication between doctor and patients. This knowledge can be used to modify training of medical students and doctors in communicating with patient.
- *Human Computer Interaction* (HCI) may benefit from theory on secondary user experience, as well as the design guidelines and new knowledge on usability evaluations.
- For *Computer Supported Collaborative Work* (CSCW) the knowledge on effects of mobile point-of-care systems on communication and collaboration between the doctor and the patients is relevant. It can be used to design better collaborative systems. In addition, the theory on secondary user experience is important as it may offer alternative views on research on CSCW systems.

Implications and relevance for practitioners

The contributions can have implications for practitioners in the software industry that develop mobile point-of-care systems.

- *Designers* may find the design guidelines useful. In addition they could find the methods for usability evaluations valuable.
- *Developers* may find the design guidelines relevant, as they can have implications for the requirements of mobile point-of-care systems.

For practitioners, a summary of the guidelines is summarized in Box 1.

Box 1. Summary of guidelines

Designing mobile point-of-care systems

The following list summarizes all the design guidelines:

General design guidelines

- Design for the secondary user experience.
- Make necessary trade-offs between primary and secondary user experience.
- Consider doctor-patient communication as an important quality criterion.

User interface design

- Create user interfaces that require little attention.
- Provide system feedback.
- Provide a GUI and/or display tailored for the patient.
- The user interface should use the language of the secondary user.
- Consider the interaction technique.
- Simplify the process.

Device design

- Make the device pocket sized.
- Use a neutral device design.
- Support gesturing and non-verbal communication.
- Increase the visibility of actions.

Implications and relevance for users

Hopefully the contributions of this thesis may have consequences for the end-users if practitioners are able to design improved systems:

- *Clinicians* will get better GUIs and more appropriate devices. They could find that the systems require less of their attention and that they communicate better with patients.
- *Patients* will get more of the clinicians' attention and communicate better with them. In addition, they will understand more of what the clinician is saying and doing, something that can improve their health outcome.

Summary

The potential implications and relevance of different contributions for different domains are presented in Table XI.

Table XI. The potential implications and relevance of different contributions for different people and domains.

	Researchers				**Practitioners**		**Users**	
Contributions	HI	Med	HCI	CSCW	Design	Develop	Clinician	Patient
Observed effects on doctor-patient comm.		•		•			•	•
Reduced face-to-face communication		•		•			•	•
Impaired non-verbal communication		•		•			•	•
Reduced visibility of actions		•		•			•	•
Changing communication practices		•		•			•	•
Spoken language is influenced		•					•	•
Guidelines for designing mobile systems	•		•	•	•	•	•	•
Designing for the secondary user experience	•		•	•	•	•	•	•
Doctor-patient dialogue as important quality criterion	•		•		•	•		
Designing the GUI to support communication	•		•		•	•	•	•
Designing the form factor to afford communication	•		•		•	•	•	•
Value and validity of evaluations	•		•	•	•			
Unobtrusive, multi-perspective recording tech.	•		•	•	•			
Encouraging and capturing user reflection	•		•	•	•			
The added value of card-ranking exercises	•		•	•	•			
Just enough simulation fidelity	•		•	•	•			

8.5. Evaluating the research

As indicated in Chapter 6, the research approach taken has a number of limitations and uncertainties. In this section the overall research is evaluated and validity issues are discussed according to Section 5.3.

Conclusion validity

Conclusion validity questions whether the method used shows a relationship between the variables that are studied.

The use of several research strategies and methods made triangulation of data possible, allowing for stronger conclusions based on several data sources. In addition, the conclusions are drawn based on four studies of different mobile systems, where a total of 36 physicians and nurses have performed 180 ward rounds. Further, a comparative evaluation approach with the use of the paper chart as a baseline makes the conclusions stronger. **This suggests that the conclusion validity is high.**

Most participants were relatively novice users of mobile point-of-care systems. Long-term effects, such as training effects and changing norms, may demonstrate that both physicians and patients may adapt to usage and overcome any hinders to good doctor-patient communication. This weakens the conclusion validity.

Internal validity

Internal validity questions whether the method used demonstrates a casual relationship between the two variables or not.

By using an experimental research strategy, most variables could be controlled. The lab-based approach has allowed control of many variables that was not been possible in the field. Within each study, all participants experienced the same experimental setup. They talked with the same patients and used the same mobile systems in the same environment. **This suggests that the internal validity is high.**

Construct validity

Construct validity questions whether the methods measure what they are intended to measure.

Health care professionals have been consulted in the development of the research design. Together with experienced sociologists, they have also evaluated the data from the ward rounds and found them to be representative instances of health care work. **This suggests that the construct validity is high.**

External validity

External validity (also known as generalizability) questions whether the relationship found can be generalized to other settings.

The samples are taken from a lab setting, which limits the external validity of the study. Further, the use of patient impersonators is a threat to external validity, as they where trained actors – not real patients – used to induce a natural reaction from the clinicians. In addition, the variation of different patient cases was limited. However, all this was necessary to increase the internal validity.

Given the variation in the tests regarding medical treatment and care given by the physicians, one may question the reliability and generalizability of the study. However, several studies show that doctors' behavior also varies in the real world (Del Piccolo et al., 2002). **Overall, this suggests limitations of the external validity.**

Ecological validity

Ecological validity concerns whether the research is representative for what happens in the real world or in real-life situations.

One open question is whether the results from the simulations can be accepted as "the real thing" – as a safe, non-intrusive, and non-compromising substitute for field observations. The answer of this question is probably not yes or no, but rather *to what degree*.

A limitation of this study is that the medication systems used in the simulated ward round did not reflect the complexity of real-life scenarios. The scenarios and patient cases had to be adapted to match the functionality that the prototype offered.

It may also be argued that the functionality of the prototypes in some studies was too sparse, and the user interface too simple. The fact that only a few physicians commented on the simplicity of the system functionality is an indication that it delivered what they expected from the scenario. On the other hand, since the scenario was simulated, the effects of the physicians' actions did not have real-life consequences. This might have influenced their behavior.

The lack of real patients and the low number of patient actors is another limitation of the study. In addition, the 'patients' did not have a medical problem, thus they did not worry about the consequences. This may have affected the realism of the interaction between the patient and physician. Because of this, the results can only be used as an indication of patient experience and a direction for further work on how people in care-receiving situations might perceive the clinicians' use of handhelds compared to paper charts.

The fact that the physical setting and scenarios were not real but invented by the researchers might be considered another limitation to this study. While real-life health care means time pressure, interruptions, risk of medical errors, decisions influencing the patients' lives, interactions with patients' fears and hopes, and need to communicate with colleagues, none of these elements were replicated in the simulated ward rounds. However, the group analyzing the realism of the consultations expressed that the physicians, in most cases, were able to act and respond realistically to the patients' complaints. In addition, the participating physicians confirmed after the tests that the scenarios and physical setting were sufficiently realistic for them to behave naturally. **Overall, this suggests limitations of the ecological validity.**

Reliability

Reliability is the extent to which another researcher would find the same answer.

Most of the data were only analyzed by one person, which is subject to interpretation bias. However, some of the data have been analyzed by two or more people, and some data fragments have been analyzed in so-called *data sessions* (Heath et al., 2010), where a group of experienced sociologists and HCI researchers have discussed and analyzed the data together to align their interpretations. In addition, different researchers have been responsible for the different studies. **This suggests that reliability is satisfactory.**

Limitations

Based on the evaluation above, the validity of the research is high, but the lack of field data hampers the external validity and makes it hard to generalize the research findings. In addition, the use of simulation-based usability evaluations has a negative impact on the ecological validity.

9. Conclusions and Further Work

The overall research aim of this thesis was:

> (…) to explore properties of mobile point-of-care systems in hospitals that are important for doctor-patient communication in ward rounds.

This was conducted by answering three research questions. The main methods used were simulation-based usability evaluations and interviews with both physicians and patients. By analyzing video and interview data from 180 simulated ward rounds by 36 physicians and nurses, the research questions (cf. Section 1.1) were answered and provided the following contributions:

(1) Observed effects of mobile point-of-care systems on doctor-patient communication
(2) Design guidelines for mobile point-of-care systems that support doctor-patient communication
(3) Knowledge on how to plan and conduct lab-based usability evaluations to maximize value and validity.

The main conclusions are presented below.

9.1. Effects of mobile point-of-care systems on doctor-patient communication

The first research question was:

> How do mobile point-of-care systems affect doctor-patient communication in ward round settings?

Mobile point-of-care systems hamper doctor-patient communication. Compared to the paper chart, mobile point-of-care systems used during the ward round require more of the physicians' attention than the paper chart. This may reduce non-verbal communication and lead to less face-to-face communication. In addition, the mobile devices make the physicians' actions less transparent for the patient. While some physicians are good at counterbalancing the negative effects, for other physicians it may hamper the communication with the patient. This can have negative consequences for patients' health outcomes.

Mobile point-of-care systems can also have a positive effect on communication. In contrast to the paper chart, it was seen that the user interface of the mobile device guided the physicians to use everyday language instead of medical language. This was more comprehensible for patients.

> **Mobile point-of-care systems in ward rounds have an impact on the verbal and non-verbal aspects of doctor patient communication. Physicians and other health care professionals using such systems should be aware of this impact and take the necessary measures to avoid negative effects.**

9.2. Designing mobile point-of-care systems that support doctor-patient communication

The second research question was:

> How should one design mobile point-of-care systems so that they support the doctor-patient dialogue?

Designers need to broaden their perspective and view the patient as a secondary user who has a secondary user experience of the mobile point-of-care system. However, designing for the secondary user can sometimes involve design trade-offs between the primary and secondary user.

Doctor-patient communication should become an assessable quality criterion. In the same way as device properties, privacy and information integration are important quality criteria for mobile point of care systems, factors such as ability to maintain eye-contact and support the dialogue with the patient, are important quality criteria. Designers and developers should have these elements in mind when designing mobile point-of-care systems. Furthermore, these criteria should be assessed before approving the systems for hospital use.

Further, the findings suggest that there are two main components that should be designed to support doctor-patient communication; the user interface and the physical form factor:

The user interface must be designed to support the doctor-patient communication. This imply that the user interface (1) requires only a minimum of the physician's attention, (2) gives sufficient system feedback not only to the physician, but also to the patient, (3) provides a display tailored for the patient, (4) provides simplified and fast work processes, (5) has an appropriate interaction technique, and (6) guides physicians to use everyday language. This will prevent the systems to become a third party in the doctor-patient communication.

The device form factor should be designed to display non-verbal communication. This suggests that the design (1) makes actions visible for the patient, (2) supports gesturing by the physician, (3) allows the physician to put the device in the lab coat pocket when not in use, and (4) has a neutral or medical equipment look-and-feel.

Doctor-patient communication is not only about the communication skills of the physician. It can also be nourished and promoted with good interaction design and smart device form factor design. Designers need to broaden their perspective and design for doctor-patient communication.

9.3. Planning and conducting lab-based usability evaluations

The third research question was:

> How should usability evaluations of mobile point-of-care systems be planned and conducted to maximize the value and validity of the results?

Use unobtrusive, multi-perspective recording techniques. These techniques, which include remotely controlled dome cameras and mirroring software, can give a good basis for detailed video analysis. This can in turn provide valid and precise understanding of physical and ergonomic aspects of mobile designs. As a positive side effect, the ecological validity will be improved.

Encourage and capture user reflection. Since think-aloud works poorly in many evaluation settings, the evaluator can encourage and capture user reflection with (1) multiple test participants, (2) comparative evaluations with multiple design alternatives, (3) short on-site interviews between design alternatives, (4) post-evaluation interviews with both physicians and patients, (5) prototypes available during the interviews, and with (6) card ranking exercises as part of the interviews.

Frame the research design with just enough simulation fidelity. For optimal cost-benefit, the physical environment, prototypes, and scenarios should be designed with *just enough realism* related to the research questions asked. The *Simulation Acceptance Model* can guide evaluators in finding the right simulation fidelity so that participants accept, commit to, and engage in the usability evaluation.

With enhanced recording techniques, better ways of promoting user reflection, and just enough realism, the value and ecological validity of usability evaluations can be improved.

9.4. Directions for further work

This work has a number of limitations and uncertainties, as described in Section 8.5. In particular, the lack of field data hampers the external validity and makes it hard to generalize the research findings. In addition, the use of simulation-based usability evaluations has a negative impact on the ecological validity.

Future research efforts should therefore validate the effects of mobile point-of-care systems on doctor-patient communication in the field. One should also investigate how these effects change over time with physicians' increasing experience with the systems.

Further, the design guidelines presented in Section 8.2 should be implemented in the design of a mobile point-of-care system. The effects of these guidelines on doctor-patient communication should be measured and compared with a baseline system.

Moreover, research efforts should investigate how to further increase the external and ecological validity of simulation-based usability evaluations.

Finally, the concept of secondary user experience described in Section 8.2 should be validated both in health care and in other domains.

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Part II

Research papers

Research Papers

Paper 1:
Methodological and practical challenges

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Usability testing of mobile ICT for clinical settings: Methodological and practical challenges

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ABSTRACT

Background: While much is known about how to do usability testing of stationary Electronic Patient Record (EPR) systems, less is known about how to do usability testing of mobile ICT systems intended for use in clinical settings.
Aim: Our aim is to provide a set of empirically based recommendations for usability testing of mobile ICT for clinical work.
Method: We have conducted usability tests of two mobile EPR systems. Both tests have been done in full-scale models of hospital settings, and with multiple users simultaneously. We report here on the methodological aspects of these tests.
Results: We found that the usability of the mobile EPR systems to a large extent were determined by factors that went beyond that of the graphical user interface. These factors include ergonomic aspects such as the ability to have both hands free, and social aspects such as to what extent the systems disturbs the face-to-face interaction between the health worker and the patient.
Conclusions: To be able to measure usability issues that go beyond what can be found by a traditional stationary user interface evaluation, it is necessary to conduct usability tests of mobile EPR systems in physical environments that simulate the conditions of the work situation at a high level of realism. It is further in most cases necessary to test with a number of test subjects simultaneously.

1. Introduction

Most Electronic Patient Record (EPR) systems currently run only on stationary computers, while empirical studies of clinical work in hospitals show that health workers are constantly on the move in a highly event-driven working environment [1]. Clinical work is information and communication intensive and highly mobile [2]. EPR content is currently to a large extent produced and utilized in point-of-care settings away from the computers through the use of paper printouts, hand-written notes, and voice memos; while actual interaction with the EPR is done while sitting down at a stationary computer. This creates an obvious potential for mobile computing in healthcare.

To best support health workers in their everyday work, the hospital's EPR system should allow for interaction with the patient's medical information at the point of care. A number of studies of existing systems have documented the benefits of mobile computing in health care [3,4], and other studies indicate additional benefits from the use of context information

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such as the health worker's location and electronic patient identification [5–7].

Moving the user interfaces of EPR systems on to mobile devices creates new challenges for system design and usability evaluation. Since its infancy at Xerox Parc in the late 1970s [8], usability testing of information systems has matured to an established practice in the software industry, with an ISO-defined common industry format for reporting test results [9]. Up until recently, most software products being tested were desktop based, i.e. single-user software running on a desktop computer with input through a keyboard and a mouse. This situation is now changing as more software is being produced for mobile devices such as mobile phones and PDAs. This creates new methodological and technological challenges.

From a usability perspective, the main difference between desktop-based and mobile computing is related to the use situation. The prototypical use situation for desktop-based applications is one-user sitting on a chair in front of a table looking at a screen with his or her hands on the keyboard and the mouse. Mobile technology, on the other hand, is to a much larger degree embedded into the user's web of physical and social life. Dourish [10] uses the concept of *embodied interaction* when referring to this. Embodied interaction, as argued by Dourish, is characterized by presence and participation in the world. As such, interaction with mobile technology is not a foreground activity to the same extent as interaction with desktop-based systems, but switches between being at the foreground of the user's attention and residing silently in the background.

The hospital as a work environment makes usability evaluations even harder, as compared to for example everyday use of mobile phones. Mobile ICT in healthcare is often integrated with a number of other ICT systems, serves a number of different user groups, and must allow for use in a number of different physical environments. Usability testing of mobile technology in healthcare consequently requires new ways of designing and doing the tests, new ways of recording user and system behavior, and new ways of analyzing the test data.

In the present paper we will address some of the methodological and practical challenges related to usability testing of mobile ICT for healthcare. This will be done by summing up our experience from two usability evaluation projects of mobile EPR done in a full-scale model of a hospital ward.

We have posed two research questions. (1) What classes of usability problems should a usability test of mobile ICT for clinical settings be able to identify? (2) What are the consequences concerning test methodology, lab setup and recording equipment? We will answer the first question by analyzing the usability issues that emerged in the two projects. The next question will be answered by analyzing what aspects of our existing test methodology, lab setup and recording equipment that contributed to the identification of these usability issues. Based on this, we will give some general recommendations for usability testing of mobile ICT for clinical settings.

We are aware of the limitations given by the low number of projects, and will discuss the threats to validity that this poses.

2. Background

2.1. *Mobile technology defined*

There is at present no consensus on a definition of mobile technology. In [11], Weilenmann does a review of the literature on mobile usability and ends with a fairly open definition of mobile technology: "...a technology which is designed to be mobile" (p. 24). For the purpose of the present analysis we prefer a more precise definition. We define mobile technology as technology that provides digital information and communication services to users on the move either through devices that are portable per se, or through fixed devices that are easily ready at hand at the users' current physical position.

Concerning computer devices, the above definition includes Tablet PCs, PDAs and mobile phones, but also opens up for ubiquitous and pervasive technologies, multi-user, and multi-device systems. It excludes the desktop computer, defined as a one-user-at-a-time stationary computer with display, keyboard and mouse.

2.2. *Usability defined*

Up until the late 1990s there was no well-established definition of usability. A long discussion in the field has led to an ISO definition of usability. ISO 9241-11 [12] defines usability as the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". An important property of usability as defined by ISO is that it is relative to the users, their goals and the physical and social context of use. This makes the definition of usability context-dependant [13], and different from context-free definitions such as that of the meter, which is the same for every user, every goal and every physical and social environment. By defining usability relative to users, goals, and environment, it becomes meaningless to talk about usability as a property of a product as such. A modern "smartphone" can have a high usability for an adult user who wants to use it for a multitude of tasks. Due to the necessary complexity at the user interface, the same mobile phone might have a very low usability for her child who simply wants to call her mother.

2.3. *Usability evaluation of mobile technology*

The physical shape of the PC has converged into two dominant forms, the desktop computer and the laptop. This *de facto* standardization makes it possible to develop software for PCs without having to care about hardware issues.

For mobile devices the situation is far more complex. We find a multitude of form factors, screen sizes, interaction technologies, and button configurations. Mobile devices range from one-button controllers for garage doors to "smartphones" with full QWERTY keyboards. They take input through different combinations of buttons, touch screens, navigation wheels, voice recognition, and pen input. Some devices have no screens, some have very small screens, some have fairly large high-resolution screens, while some even have two screens. From a usability perspective, the obvious implication is that every evaluation of a mobile application or service will at the same time be an evaluation of the device(s) on which it runs.

Since Weiser coined the term "ubiquitous computing" in the early 1990s [14], there have been a number of usability evaluations of non-desktop systems, both under controlled laboratory conditions (e.g. [15]) and through field trials (e.g. [16]).

A number of studies have compared stationary usability testing and field testing for mobile technology (e.g. [17,18]). The usability tests took place in "traditional" usability laboratories, and consisted of testing the mobile application in a stationaries use setting. The field trials involved following the users in their natural setting. The studies concluded that both evaluation methods have their specific pros and cons, and that they complement each other. Usability tests are better at identifying details of the interaction, while it lacks in realism. Field trials are better at identifying contextual matters, but it is often difficult to get feedback on specific user interface issues.

3. Method

3.1. *A usability laboratory for mobile ICT in medical settings*

As part of a national research initiative on health informatics in Norway (NSEP), we got funding to build a usability laboratory for evaluation of mobile applications in the health domain. Being aware of the drawbacks of traditional desktop-based usability tests for mobile technology, we started out by conducting a comparative usability evaluation to verify the results of Kjeldskov et al. [17]. The study [19] verified their results and motivated the construction of a laboratory that allows for a large degree of realism. The health domain differs from many other domains in that field trials are very difficult. This is due to medical, ethical and practical reasons. This gave an additional motivation for building a usability laboratory, and not relying on field tests.

To compensate for the lack of realism in traditional usability tests, we have built a laboratory with movable walls in a $10\,m \times 8\,m$ room that allows for full-scale simulations of different hospital settings. Our hope is that this approach will give us the best of desktop usability tests and field trials. The laboratory has been used for testing of mobile and ubiquitous computing [20], and for doing drama-based participatory design [21]. In Fig. 1 we see a typical setup of the laboratory where the movable walls and doors are configured to mimic a section of a ward in an average Norwegian hospital. The rooms are equipped with patient beds, chairs and tables to create a high level of realism. We have consulted health workers in this process.

For recording of user data we use a fully digital Noldus video-recording solution with our own adjustments and extensions. We currently have three roof-mounted remote control cameras, a number of stationary cameras, wireless "spy" cameras, wireless microphones, an audio mixer, and software solutions for doing remote "mirroring" of the content on the mobile devices. The recording equipment allows us to integrate a number of video and screen capture streams into a high-definition video digital recording. At the most we have integrated in real-time three video streams and live screen capture from seven mobile devices; together with audio from four microphones.

4. The two experiments

We will report here from two usability evaluations done in the usability laboratory by the authors. Both evaluations were controlled experiments exploring the potential for mobile and ubiquitous computing in the hospital. The aim of the two studies was to compare specific technological solutions. The results from the comparison tests have been reported elsewhere [22,23], while the consequences for test methodology were not discussed. We will here summarize the lessons learned from the two experiments concerning usability evaluation methodology.

4.1. *Experiment 1: combining handheld devices and patient terminals*

A number of new hospitals now install bedside terminals for the patients. Such terminals are currently to a large extent used for entertainment and web browsing. The patient terminal is basically a PC where all input and output is done through a touch screen. The patient terminal is mounted on a movable arm (see Fig. 2), so that it can be moved according to the patient or staff's preferences.

In cooperation with one of the vendors of these terminals, we explored the potential for letting physicians use handheld devices (PDAs) as input device for the bedside terminals. Seven different prototype PDA user interfaces were implemented, in

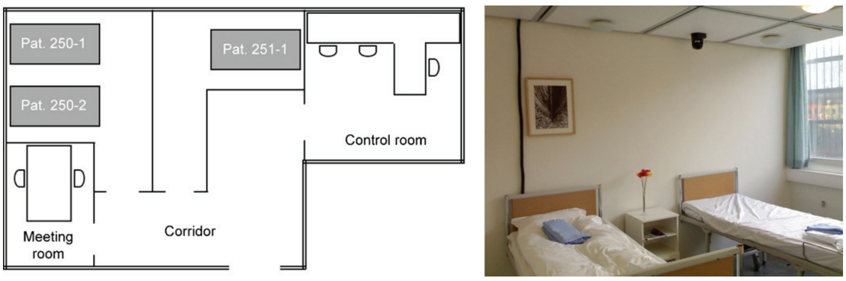

Fig. 1 – The usability laboratory.

Fig. 2 – A bedside patient terminal.

addition to a baseline solution where all interaction was done directly on the patient terminal touch screen. The eight alternative designs were tested on a scenario where a physician uses a bedside terminal to show X-ray images to a patient. Fig. 3 shows two of the prototypes. On the solution to the left, the physician selects an X-ray image by dragging it to a terminal icon on the PDA. On the solution to the right, the physician uses the PDA as a remote control to navigate in a menu on the bedside terminal.

Due to patient safety and privacy issues, we were not allowed to test the prototypes *in situ*. The usability tests were done in our usability laboratory with a replication of a patient room with a hospital bed, a touch screen bedside terminal, and a PDA. Due to the nature of the scenario, the tests were done with pairs of users, one physician and one patient. A total of five pairs were recruited. Fig. 4 shows the recorded video from a usability test of a third design alternative. The integrated video has two video streams to the left and a mirror image of the PDA to the right.

After having tried out all versions, the physicians and patients were asked to rank the different solutions by sorting cards representing the alternatives. They were asked to give reasons for their ranking.

The ranking session for each alternative was recorded, and the post-test interviews were transcribed. The interviews were then analyzed in search of recurring patterns. The comments made in the tests and during the card rankings gave insight into the factors that were perceived as influencing the usability. All factors listed below were found for all pairs of testers.

4.1.1. *The graphical user interface*

The usability of the graphical user interfaces (GUI) on the two devices had an important impact on the overall usability. When the users were unable to comprehend the user interfaces, or when they were awkward to use, the corresponding design alternatives got a low ranking.

The usability of the graphical user interface is here defined as what is normally evaluated with a stationary usability test on a desktop computer. It includes the visual design, the ease of use of the interactive screen elements, and factors such as affordance, constraints, visibility, feedback, and interface metaphors. The simplicity of the GUI was explicitly appreciated by many of the users.

4.1.2. *Screen size and ergonomics of the patient terminal*

All participants reported that the screen of the patient terminal was large enough to show X-ray images, while the screen of the PDA was too small for this purpose. Having the patient terminal positioned by the bed within arm's reach from the patient made the X-ray images easy to see for both physician and patient. The terminal was easy to operate for the patients through touch, while some physicians were uncomfortable with the solution, as they had to bend over the patient's bed to reach it. Some physicians commented that a good thing about the PDA-based design alternatives versus the baseline alternative (no PDA) was that they no longer had to bend over the patient's bed to operate the terminal. This influenced their ranking of the alternatives in favor of the PDA-based solutions.

4.1.3. *Shared view versus hiding information on the PDA*

One recurring issue during the interviews was whether the selection list should be on the patient terminal or only on the PDA. Four of the design alternatives had the list of X-ray images present on the patient terminal all the time, while the remaining four had the list only on the PDA. Most physicians thought at first that there was no point in hiding the list for the patient, while some meant that the list could distract the patient. Some were afraid that the patients would interpret information on the list without having the skills to do so.

Most of the patients initially wanted the list to be present on the screen. They wanted to see an overview of the images and felt that the physician was keeping secrets for them when the list was not present. Two of the patients changed their mind during the tests, and felt that the list took too much attention. They felt that it was easier to focus on the X-ray images and the physician when the list was not present. One patient felt that he had enough confidence in the physician that it did not matter whether the list was present or not.

Fig. 3 – Two of the eight design alternatives that were evaluated.

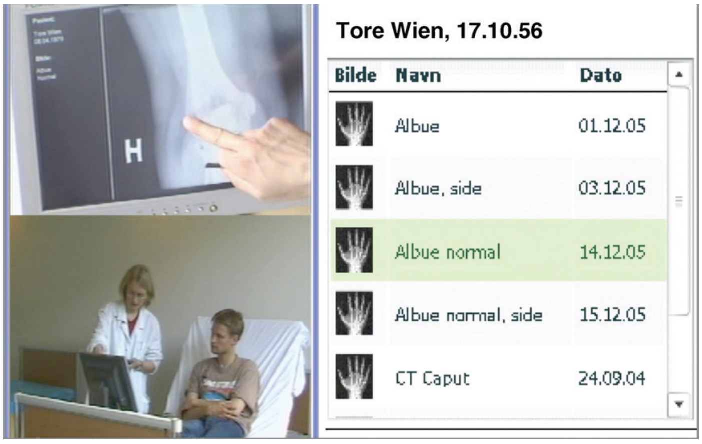

Fig. 4 – The physician uses her PDA to select an X-ray image to show to the patient.

The evaluation was inconclusive as to whether the physicians should be "allowed" to have "secret" information on the PDA. The answer to this question is not relevant here, what is important are the arguments used in the preference ranking. The arguments for allowing some of the information to reside only on the PDA were related to optimal use of the screen for showing X-rays, and hiding of unnecessary information. The arguments for sharing all information on the patient terminal were related to trust and overview.

4.1.4. *Focus shifts and time away from the patient*

Almost all physicians commented that the PDA became an extra device to focus on. One of the physicians reported: "I get two places to see, and I experience that I speak less to the patient. I have to share my focus between there [patient terminal], there [PDA], and the patient. It's quite demanding, and I have to share my focus between three different levels".

The results from the usability test showed that the change of focus between the PDA and the patient terminal was quite demanding for most of the physicians, and it became a disturbing element in the communication with the patient. The arguments made by the test subjects during the preference ranking indicate that design alternatives requiring many focus changes between PDA and patient terminal were rated lower than less demanding design alternatives.

When the physicians and the patients looked at or used the same screen, they felt that they were communicating on the same "level". When the physicians started using the PDA, some of them felt that it became a disturbing element in the conversation and that they now were communicating on different "levels".

4.2. *Experiment 2: automatic identification of patients at point of care*

The aim of this evaluation was to assess and compare the usability of different sensor-based techniques for automatic patient identification during administration of medicine in a ward.

Lisby et al. [24] analyzed the frequency and cause of medication errors in a Danish hospital. They found that 41% of the errors were related to administration. Of these, 90% were caused by wrong identification of patients. Currently, few hospitals have computer systems supporting the administration of medicine at the point of care. A recent study of the use of technology in drug administration in hospitals shows that only 9.4% of US hospitals have IT systems that allow the nurses to verify the identity of the patient and check doses at the point of care [25].

During drug administration, a health worker (typically a nurse) distributes prescribed medicine to ward patients. The nurse also signs off on the respective patients' medication chart that the medicine has been administered and taken. For simplicity, the chosen test setup involved only two patients. Moreover, it was assumed that the patients were located in their respective beds throughout the whole scenario. For simplicity, it was also assumed that the correct medicine dosage for the respective patients was carried in the health worker's pockets. Fig. 5 shows a health worker in front of the first of the two patient beds.

The problem being addressed in the developed prototypes was that of identifying the correct patient at the point of care. A typical solution for patient lookup on a PDA or bedside terminal would be name search or selection from a patient list. These are activities that take time, and where the potential for error is large. By adding new ubiquitous-computing technology to the mobile EPR, such as token readers or location sensing, there is a potential for automating patient identification.

Four different design solutions to the problem of automatic patient identification were compared. The four alternatives were the 2×2 possible combinations of two sensing technologies and two device technologies. The two sensor technologies were barcodes (token-based) and WLAN positioning (location-based). The WLAN positioning system used consisted of directional antennas in the ceiling that continuously detected the physical position of all WLAN devices in the room to an accuracy of approx. 0.5 m. The two device technologies were

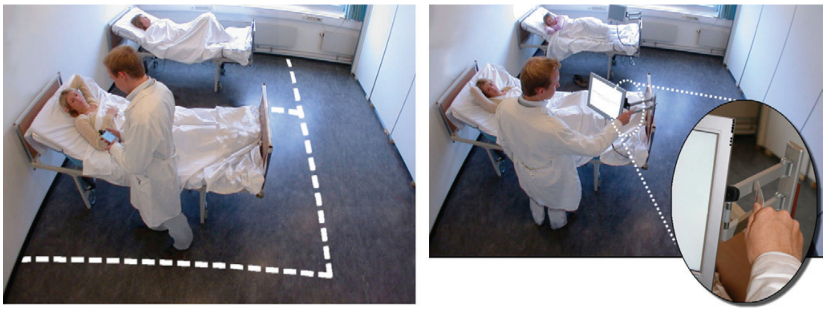

Fig. 5 – Location-based and token-based interaction.

wireless PDAs (mobile) and bedside touch-screen terminals (stationary). An implicit assumption in the prototype implementations was that the computing devices could retrieve medication charts from an EPR system. The user interface for the medication chart was made extremely simple, as the focus of the study was not on medication charts, but on automatic identification of patients.

A total of eight Norwegian health workers (seven nurses and one physician) were recruited from a local hospital. We had two persons with experience from health care simulate the two patients. The test participants were also encouraged to interact with the persons simulating patients just as they would do in an everyday work situation.

As in Experiment 1, the test subjects were asked to rank the four alternatives while explaining their rankings. The transcripts from the ranking sessions were analyzed in search of factors that influenced their ranking. These are summarized below.

4.2.1. *Time on computer devices versus time on patient*

Many test participants expressed a general concern that cumbersome information navigation would require them to pay too much attention to the computer devices, rather than attending the patient. They consequently all saw the benefit of automatic patient identification.

The two location-based interaction techniques got a high ranking. These design alternatives took advantage of the user's natural mobility in the physical environment. The fact that these techniques allowed patient identification to occur in the background of the user's attention can be viewed as an important reason for their high rating. According to one test subject, retrieving medication information based on a caregiver's physical location "gives meaning simply because you necessarily have to be with the patient when administering his medicine."

In order to retrieve patient information via tokens (i.e. barcodes), the users had to explicitly scan them. The test participants who preferred location-based interaction to token-based interaction argued that barcode scanning took attention away from the patient and the care situation.

4.2.2. *Predictability and control*

Earlier work on context-aware/ubiquitous computing has pointed out that autonomous/automatic computer behavior often comes at the cost of user control [26,27]. The conducted usability tests revealed similar tendencies. Users that preferred token-based interaction to location-based interaction found that getting computer response as a result of an explicit and deliberate action gave them a feeling of greater control over the application. According to some test participants, the feeling of control over the application made the computer system seem (quote) "safer" to use. In other words, it made the users more certain that they were signing off on the correct patient medication chart.

We found that the potential lack of control some users experienced when testing the location-based solutions was related to the fact that the zones in the room were invisible. The system "magically" knew when the physician was near a patient. Despite the lack of control that many users experienced with the location-based solution, many were willing to give up control as long as it made patient identification easier.

4.2.3. *Integration with work situation*

Most test subjects commented that when administering medicine in their everyday work, they were accustomed to informing the patient verbally what medicine he or she was given. Many of the test participants therefore saw an additional benefit of having the opportunity to visually show medical information to the patient via the shared screen of the bedside terminal. Accomplishing this via the small screen on the PDA was experienced as being far more cumbersome. The PDA, however, was not found more unsuited for accessing and signing off on electronic medication charts, per se. Nevertheless, the perceived positive effect of having a shared computer screen left the majority of participants with the impression of getting the job done in a more satisfactory way with fixed bedside terminals.

Several test participants pointed out that another benefit of using stationary patient terminals versus a portable device was that it allowed them to have both hands free. This was seen as important as they often perform tasks at point of care that require both hands free (e.g. hand over medicine, help patients in and out of their beds). Based on this, the majority of the test group found the fixed bedside terminals to be more seamlessly integrated with the overall work situation, while the PDA imposed more of a physical constraint.

One of the potential drawbacks of the implementation involving a stationary device, as pointed out by test participants, was related to privacy. When using a shared screen it is also possible for others (e.g. patients and visitors) in the room to see the information.

While not found to be an important criteria for the chosen test scenario, a number of test subjects pointed out that they often consult the patient chart of a given patient prior to visiting him or her. This is done in order to get the latest, most updated information on that patient. Many test subjects therefore saw the added value of having a mobile computer device that allowed them to access patient information anywhere in the hospital.

5. Factors that affect the usability of mobile EPR

A number of factors that affected the overall usability were identified in the two experiments. We have grouped them into three large classes: GUI usability, physical and bodily aspects of usability, and social aspects of usability.

5.1. *Usability of the graphical user interface*

In the two experiments, relatively few usability issues were caused by bad GUI usability. This is probably due the simplicity of the prototypes. The simplicity of the GUI in the prototypes was appreciated by the users, but in more realistic mobile EPR system the user interfaces will be more complex and more of the usability problems will probably be due to problems in the user interfaces.

5.2. *Physical and bodily aspects of usability*

One could argue that usability problems caused by the GUI have their roots in a mismatch between the graphical user interface and human cognition. In a similar fashion, one could argue that there is a class of usability problems that have their roots in a mismatch between the physical aspects of the systems and the human physiology. The latter are often referred to as ergonomic problems, but for mobile ICT it also includes issues such as the accuracy of sensing technology. In the two experiments there were a number of physical and bodily issues.

Both experiments had issues related to screen size. In the first experiment, the PDAs were found to be ill suited for showing X-ray images, while in the second experiment large screens were preferred for showing medication lists to patients.

Both experiments also had issues related to body movement and the use of hands. In the first experiment some physicians commented that a good thing about having a PDA was that they no longer had to bend over the patient's bed to operate the terminal. In the second experiment, some users preferred a bedside terminal because it allowed them to have both hands free for other purposes.

The most important aspect of mobile ICT is that it supports human mobility by allowing for computer access "any time, anywhere". The simplest way to achieve this is by letting the user carry the devices with them. In the second experiment, some of the users preferred PDAs because it allowed them access while on the move. In Experiment 1 there was a need for large screens to show X-ray images, and it was not possible to combine this with mobility. In that case, support for mobility had to be weighted against other system requirements.

5.3. *Social aspects of usability*

Mobile technology is with the user in his/her "life world", which in most cases is a social world. Human life is to a large degree life with other humans, and mobile use therefore often happens in contexts with other people present. This is to a large degree the case for work in healthcare. Mobile devices and services are often used to communicate with other people or to coordinate shared activities, but they also play a role in the social interaction with other people.

In the two experiments we found a number of usability issues that were related to social aspects of the use situation.

In both experiments there were issues of shared versus private view of displays. These issues were caused by the social aspects of the clinical setting. There are certain parts of a physician's display that should be "off limits" to patients, such as medical data about other patients. However, in some situations in the experiments it was required that patients and physicians should have a shared view.

In both experiments it was found that the system's effect on the physician–patient face-to-face dialogue became an important usability issue. In this case, the usability of the system was affected by how the human–computer interaction matched the timing of the human–human interaction. If the human–computer interaction took too long and required too much mental effort, it reduced the quality of the human–human interaction, and as a consequence became a usability problem with the system.

Good and bad overall usability in these cases were not only due to GUI design and ergonomics, but to what degree the system matched the requirements created by the social aspects of the situation.

5.4. *Specifics of each use situation*

For all three aspects of usability; GUI, ergonomic and social; it is not the match with the users as such that matters, but the match with the use situation. In Experiment 2, it was important for the physician to have both hands free; while in Experiment 1 this was not important, even if the PDAs were the same. The difference in usability was not due to the ergonomics of the devices as such, but due to the different tasks and use situations in the two experiments.

The contextual nature of usability should not come as a surprise as the ISO standard [12] defines usability in relation to the specifics of each context of use: "*...with which specified users achieve specified goals in particular environments*".

6. Consequences for usability testing of mobile EPR

Based on the identified factors that affect the usability of mobile EPR, we will present a set of recommendations concerning usability testing of such systems. These recommendations come in addition to accepted best practice for usability testing and reporting as defined in the ISO/CIF document [9]. For all usability testing it is important to identify the right user group(s), make tasks that are realistic, and create a physical and social test environment that mimics that of the intended use situation. In addition, test scenarios and tasks must be built on studies of work practice, and their realism must be verified by the test subjects [13]. Usability testing of mobile EPR adds some additional challenges.

6.1. *Usability of the graphical user interface*

The GUI is a common source of usability problems in all ICT systems. Most mobile ICT systems for clinical use will have one or more screens with a graphical user interface. The device screens might be smaller than that of a typical PC, but we will still be faced with GUI usability issues very similar to those of desktop computing.

When the mobile-EPR GUI is complex, we recommend doing a separate desktop usability test of the system prior to a full-scale usability test. By testing the GUI separately, it is possible to cover more system functionality in one test and to get feedback on GUI details such as menu structure, navigation, wording, information architecture, screen layout, and font size. It is possible to use the same test subjects both for GUI test and full-scale test, but we recommend using different test subjects, as prior exposure to the product will reduce the validity of the test results.

A full-scale usability test of mobile EPR will also implicitly test the GUI. Much can be learned from studying the user's interaction with the GUI in a full-scale test. A desktop usability test should not be seen as a substitute for recording and analyzing the GUI interaction in full-scale tests. Some aspects of GUI usability will only appear when the tasks and work environment are realistic, and it is necessary to study the details of the GUI interaction to identify these issues.

To be able to identify GUI-related usability issues, it is necessary to record for later analysis the screen content of the devices and the user's interaction. For mobile technology it is not possible to use a video scan converter, as handheld devices have no video-out features. We have used three different techniques for recording GUI content and interaction on mobile devices.

(1) Some operating systems (e.g. Microsoft Windows Mobile, Symbian) allow for "mirroring" to a PC over WLAN through third-party software. This has allowed us to get digital video recordings with the screen content integrated with video from the lab cameras. The recording in Fig. 4 from Experiment 1 is an example. It is a real-time mix of two video sources and a "mirror" of the PDA content.
(2) In some cases the handheld devices or their operating systems will not allow for "mirroring". For those cases we have made use of a homemade docking device with a miniature wireless camera. Fig. 6 shows the device to the left and an example from a resulting recording to the right.
(3) For larger devices it might be necessary to allocate a video camera to get the details of the user's interaction. The top left part of the recording in Fig. 4 is from a roof-mounted camera that was fixed on the bedside patient terminal. In this case, the camera also captured the screen content, and eliminated the need for software mirroring of that display. When mirroring handheld devices one loses the details of the finger interaction. If possible, a roof-mounted camera should be used for following the user, and capture the details of the interaction with the device.

6.2. *Physical and bodily aspects of usability*

From the conducted experiments we learned that replicating the physical environment of real hospital settings is essential for producing valid results. For example, using human actors to represent patients (as apposed to more abstract representations or "imaginary" patients) and placing them in actual hospital beds, is crucial in order to simulate how mobile technology accommodates point-of-care situations and the interaction between clinicians and patients.

We also found that mimicking the physical configuration of an actual clinical environment can be used to guide the test subjects through a scenario. For example, by using two different rooms (a ward corridor and a patient room) and two patient actors in Experiment 2, physical movement between various locations and patients became a natural part of the scenario. This was essential for understanding the extent to which the precision of the positions sensors met the requirements of the users.

Fig. 6 – Capturing interaction with a wireless camera.

Feedback from the hospital workers participating in the experiment suggest that the perceived usability of the different techniques to a large extent was influenced by the way these configurations accommodate the changing physical and social conditions of the work situation. Often, this was related to subtle qualities of the designs that participants discovered by being able to relate the prototypes to a concrete physical environment. This also suggests that test subjects do not separate between usability flaws that are software-related and issues that are related to ergonomic aspect of the designs.

We recommend doing usability tests of mobile EPR in physical environments that mimic the hospital setting to a high degree of realism. The ideal setting is an unused part of a hospital ward that can be instrumented with cameras and other equipment. If no such environment is available, it is important that the test area has enough floor space to allow for realistic mobility. It is also important that the rooms are equipped with furniture to make realistic physical constraints on the users' mobility. In addition, the setting should be equipped with artifacts from the real-world counterpart, such as paper, pencils, medical instruments, and medication.

The ergonomics of a device is to a large extent related to how it fits in with all the other artifacts at the ward. As an example, some aspect of the clinical situation might make it important that a device allows for one-hand input, but this will not become evident in a usability test unless the health worker is actually using the other hand for some other purpose. Without real artifacts in the laboratory setup, the user might have both hands free during the test. The test results will then be invalid with respect to the ergonomics of the device, as two-hand input will not be possible in real life.

To be able to capture the physical aspects of interaction in scenarios involving physical mobility, we recommend the use of multiple roof-mounted dome cameras that can be controlled during the test. The details of physical interaction are often subtle, and we recommend allocating one person to control the cameras during the tests to track the users.

6.3. *Social aspects of usability*

The findings from the two experiments point to the importance of getting the social aspects of the use situation right. Usability issues, such as the effects on the quality of face-to-face communication, cannot be measured unless usability tests include multiple users simultaneously. We recommend that the use scenarios for mobile EPR include enough user roles to be able to capture the social context of the use situation. This will differ from system to system. In some cases one might only need a physician and a patient, while in other cases we need to do tests with teams of health workers.

It is important to make sure that the communication between the users is captures for later analysis, both the verbal and the non-verbal. Good sound quality is essential for capturing the verbal communication. We recommend one miniature wireless microphone for each test subject. An audio mixer is necessary, as most recording software only allows for stereo sound input.

To capture the non-verbal communication, it is important to make sure that there are enough video cameras to be able to follow the test subjects around during the usability test. This is very similar to the requirement concerning video capture for device ergonomics.

6.4. *The need for flexibility*

The hospital is a very heterogeneous place concerning physical work environments. Looking beyond the requirements for each usability test, there is a need to make a usability laboratory for mobile EPR flexible enough to be able to simulate a number of different physical environments. These environments will differ in floor plan, furniture and artifacts. In our laboratory, we have installed movable walls that allow for easy reconfiguration. We have found this approach very useful as it saves us time setting up the physical environment for new usability tests. Based on our experience, we recommend that a usability laboratory for mobile EPR is constructed to allow for easy reconfiguration of floor plan, furniture and artifacts.

7. Discussion

The analysis and recommendations in this study are based on a limited number of tests with a limited number of test subjects. In addition, the experiments were done with very simple prototypes in simplified use scenarios.

The experiments have allowed us to identify some usability issues for mobile EPR, but our findings should not be seen as an attempt at making a complete list of such issues. More studies of mobile EPR are necessary to get a more complete picture of the usability challenges for this class of systems.

We have concluded that the overall usability of mobile EPR is caused by far more than the graphical user interface. We are confident that this will apply also to other mobile ICT systems for clinical settings. We consequently believe that our general recommendations, to simulate and record the physical and social aspects of mobile ICT for clinical settings, will be valid for future evaluations.

8. Conclusion

Clinical work in hospitals is information and communication intensive and highly mobile. Health workers are constantly on the move in a highly event-driven working environment. Most current Electronic Patient Record (EPR) systems only allow for access on stationary computers, while future systems also will allow for access on mobile devices at the point of care. While much is known about how to do usability testing of stationary EPR systems, less is known about how to do usability testing of mobile EPR solutions for use at the point of care.

In two lab-based usability evaluations, we found that the usability of the mobile EPR systems to a large extent were determined by factors that went beyond that of the graphical user interface. These factors include ergonomic aspects such

Summary points
What is known about the subject:

- Clinical work in hospitals is information and communication intensive and highly mobile. Health workers are constantly on the move in a highly event-driven working environment.
- Most current Electronic Patient Record (EPR) systems only allow for access on stationary computers, while future systems will also allow for access on mobile devices at the point of care.
- While much is known about how to do usability testing of stationary EPR systems, less is known about how to do usability testing of mobile EPR solutions for use at the point of care.
- Few usability laboratories allow for testing in full-scale replications of hospital environments.

What this paper adds/contributes:

- The usability of mobile EPR systems is to a large extent determined by factors that go beyond that of the graphical user interface. These factors include ergonomic aspects such as the ability to have both hands free; social aspects such as to what extent the systems disturbs the face-to-face interaction between the health worker and the patient; and factors related to how well the system integrates with existing work practice.
- To be able to measure usability factors that go beyond what can be found by a traditional stationary user interface evaluation, it is necessary to conduct usability tests of mobile EPR systems in physical environments that simulate the conditions of the work situation at a high level of realism.
- To get valid results from usability tests of mobile EPR systems, it is necessary to make sure that the use scenarios are realistic. This often means that the tests must be run as role-plays with multiple stakeholders as participants, e.g. physicians, nurses, and patients.
- Due to concerns of privacy, ethics, and the possible fatal consequences of error, usability tests of EPR systems can rarely be done *in situ*. To be able to get valid results from usability tests of mobile EPR solutions, it is therefore necessary to equip usability laboratories with full-scale models of relevant parts of the hospital environment. As the hospital is a very heterogeneous environment, such laboratories should allow for easy reconfiguration of the floor plan.

as the ability to have both hands free; social aspects such as to what extent the systems disturbed the face-to-face interaction between the health worker and the patient; and factors related to how well the system integrated with existing work practice.

We conclude from this that to be able to measure usability factors that go beyond what can be found by a traditional desktop user interface evaluation, it is necessary to conduct usability tests of mobile EPR systems in physical environments that simulate the conditions of the clinical setting at a high level of realism. To get valid results from usability tests of mobile EPR systems, it is further necessary to make sure that the use scenarios are realistic. This often means that the tests must be run as role-plays with multiple users simultaneously, e.g. physicians, nurses and patients.

Due to concerns of privacy, ethics and the possible fatal consequences of error, usability tests of EPR systems can rarely be done *in situ*. To be able to get valid results from usability tests of mobile EPR solutions, it is therefore necessary to equip usability laboratories with full-scale models of relevant parts of the hospital environment. As the hospital is a very heterogeneous environment, such laboratories should allow for easy reconfiguration of the floor plan.

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Paper 2:
Techniques and considerations for lab-based usability evaluations

Authors: Ole Andreas Alsos and Yngve Dahl

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Paper 5:
Effects of mobile devices in ward rounds

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Doctors' Concerns of PDAs in the Ward Round Situation

Lessons from a Formative Simulation Study

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Keywords
Mobile computing, PDA, handheld, distractions, physician-patient communication, point-of-care, bedside computing, usability evaluation

Summary
Background: Healthcare professionals in hospital care increasingly use small-screen handheld computers. Studies that have investigated doctors' concerns about handheld usage have mainly focused on technical, organizational and performance issues. Very few have looked at the effects of Personal Digital Assistants (PDAs) on the interaction between physician and patient.
Objective: The aim of this study was to explore the effects of PDA usage on the physicians' prescription work, their concerns about using it in point-of-care situations, and the effects on the patient-physician dialog.
Methods: We used a qualitative and comparative approach where 14 physicians each carried out four simulated ward rounds in which they modified the medication of patient actors using a paper-based medical chart and three versions of a PDA-based system. We analyzed ward round video recordings, semi-structured interviews with the doctors, and focus group using approaches based on ethnomethodology and grounded theory.
Results: Physicians used PDA and paper differently. Physicians' actions, as well as their non-verbal communication, were less transparent and clear for the patient when using a PDA. Doctors were worried about distractions from the handheld device and about a negative impact on the physician-patient conversation. In general, physicians were more comfortable with paper, but preferred PDA because it offered an *undo* function and reduced the need to memorize drug names and dosages by providing concrete alternatives in the user interface.
Conclusions: Despite the many benefits, PDA usage at the point-of-care comes with the increased risk of distractions for physicians and can cause a negative patient experience. Designers of point-of-care systems need to be aware of, and address, the problems with handhelds and learn from the attributes and access capabilities of paper charts.

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1. Introduction

It is generally acknowledged that the quality of clinical work depends upon access to high-quality laboratory and imaging services, and on information systems that support and document the healthcare activities [1]. Since ward personnel work in teams, and teams share responsibilities for more than one patient, frequent interruptions and the switching between different patient problems and tasks characterize the work. Because patients are frequently incapacitated by their condition, much of the work occurs at the bedside and not in front of a desktop computer. As with all patient-centered work, care must be taken to inform and be informed by the patient.

Since the advent of PDAs and handheld computers, it has been assumed that such devices will become of great value to health care personnel. The prospect of bedside computing devices opens up the possibility of instant access to up-to-date knowledge sources as well as to patient records. Likewise, handheld computing devices that are coupled to the hospital network could be used for communication and coordination between health care personnel. PDA-type devices that offer ubiquitous access to knowledge, procedures, code registries and medication databases are now offered as commercial products that any clinician may purchase [2].

The use of computing devices at the bedside is not only a case of interaction between a health care professional and a computer, but also a meeting with the patient. However, patients' attitudes towards health care services are changing as they become more educated consumers and assume a more participatory role. Reflecting this, problems with delivering care are increasingly rooted in difficulties with communication between physician and patient [3, 4]. To adapt to this change, health care personnel must put greater emphasis on understanding the patients' needs and the perspectives they have of their condition. These insights can only be achieved by communicating more effectively with the patient [5, 6]. The point-of-care is a situation where such high-quality communication can take place. Any technological device that is in use should not preclude, but rather assist in more effective communication.

However, it has been shown that the use of computers in the consultation room influences how patients perceive the quality of the consultation [7, 8]. Also, doctors' use of handheld computers might influence their abilities to commit themselves to the dialog with patients [9, 10].

The present study was conducted to explore the effects of PDA usage on the physicians' prescription work, concerns about using it in point-of-care situations, and the effects on the patient-physician dialog.

Fig. 1 Frame from recorded video data displaying physicians' interaction with GUI (left), physical device (upper right), and overall care situation (middle and lower right)

2. Background

Electronic medical records and other healthcare IT systems are increasingly seen as remedies to curb costs and improve quality and patient safety. Seen from the perspective of the *Technology Acceptance Model*, which models how users accept and use technology [11], accessibility to information sources is considered one of the most critical factors in influencing health care professionals to use such systems [12]. Enabling interaction with patients' medical record via handheld devices is a very attractive option. Moreover, a review of studies comparing paper and PDA showed that handhelds in general are a faster and preferred alternative to paper-based data collection [13]. However, paper-based media has much richer interaction capabilities and accessibility compared to electronic media, such as PCs and PDAs [14].

Houston et al. [9] reported on how American patients perceived doctors' use of handheld computers. They found that only 10% of the patients disliked the idea of handhelds in the examining room. However, only 9% (eight patients) reported that their doctor actually had used a handheld in the examining room. The study also included the residents. Twenty-three percent of them reported that they had reservations about using a handheld in front of the patient, but the study did not mention reasons for their opinions.

Based on a series of focus groups, McAlearney et al. [15] reported on doctors' experience with handhelds in clinical practice. The doctors' main concerns about handhelds were about the device itself (loss, breakage, and reliability), information security, and user-dependency. However, the most interesting concern in this context was their fear that clinical practice might change for the worse. Doctors were worried that patients would have negative views about them using handhelds or think the doctors were incompetent if they needed to use one. In addition, some were worried that enthusiastic colleagues would focus too much on the device and forget to care about the patient.

In a series of experiments with bedside computers in a full-scale usability laboratory, health workers and patients were observed while simulating clinical encounters [16, 17]. In these experiments, some of the participating physicians reported that the handheld was a disturbing element in the conversation with the patient [16]. The same observation was made in experiments that compared bedside methods for automatic identification of patients to access medical information [17]. Here, health workers clearly preferred design alternatives that did not require them to shift their attention away from the patient.

In most studies investigating doctors' (or patients') concerns about handhelds, reliance was placed on methods such as interviews [18, 19], focus groups [15], or surveys [9]. However, these methods collect user opinions outside the context of use. This can cause important concerns to be overlooked and lead to irrelevant concerns being promoted as important.

3. Methods

The approach used in the current study was to collect users' opinions and reflections in a controlled environment. We asked 14 doctors to use and compare four methods, three PDA-based and one paper-based, for managing patient's medication during patient visits in a simulated hospital environment with patient actors. By interviewing them immediately afterwards in the same environment, we promoted user reflection. The method produced rich qualitative data on the usage of and concerns about handhelds at the point-of care. The interview data were analyzed using an approach based on grounded theory. To complement and triangulate the findings from the interviews, we recorded audio and video data from each of the 56 patient visits, which were analyzed using an ethnomethodological approach. In addition, we asked patients about their reflections in a focus group.

This section describes the experimental setup and design, the test procedure, and how the data were analyzed.

3.1 Experimental Design

The general setup was a simulated patient visit in a "hospital ward simulator", where a physician made changes to the medications of patient actors using four different information devices; three PDA-based medication systems and one paper-based medical chart. The main purpose of the study was twofold; to investigate the physicians' prefer-

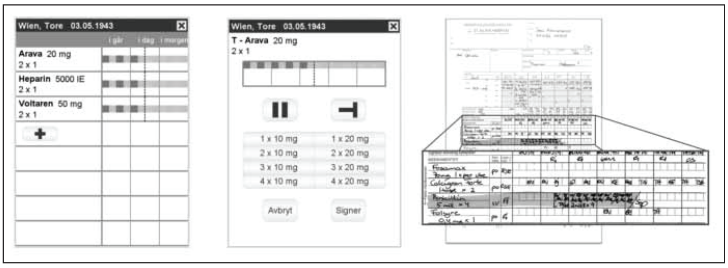

Fig. 2 Screenshots from the stylus prototype showing the main screen (left), the change/pause/cease screen (middle) and an example of the paper chart used in the experiments (right)

Fig. 3 The three prototypes (left) and the paper chart (right) used in the experiments

ences for different interaction techniques, and to analyze their concerns about PDA usage. A more thorough presentation of the experimental design, its limitations, and methodological reasoning was presented in an earlier article [20].

3.1.1 Location and Recording Equipment

The tests were conducted in a usability laboratory for testing medical systems located in a research center at a regional hospital site. The details on the laboratory have been previously reported [21].

The PDA's screen content was wirelessly mirrored, and mixed real-time together with video streams from ceiling-mounted cameras and audio streams from wireless microphones (▶Fig. 1). Altogether, the recorded video provided details about the physicians' interaction with the graphical user interface, their interaction with the physical device, and the overall care situation.

3.1.2 Handheld Information System

It has been shown that if one puts too much effort into prototype functionality and graphical user interface (GUI), the usability test participants will discuss usability problems with regard to the GUI rather than on usability problems concerning physical (e.g. device size) and social issues (e.g. ability to attend to the patient) [21]. We therefore deliberately designed a simple user interface with little functionality to provoke reflections regarding the social issues of using handheld devices at the point-of-care. The PDA-based prototype was deliberately designed with only four functions; prescribe a new drug and change, pause, or cease an already prescribed drug. Screenshots of two of the screens are shown in ▶Figure 2. The user interface was designed using *minimal attention user interface* principles [22], and based on best practice in visualization and user interface design [23, 24]. Symbols and icons used were already well known from the paper chart.

Three versions of the prototype were developed, each adapted for interaction with stylus, finger or device buttons respectively (▶Fig. 3). The differences between them were minor; the *finger* prototype had larger GUI-buttons than the stylus prototype, and the *button* prototype had an indicator moving between GUI-buttons as the user navigated through them with the hardware buttons. For the purpose of this study the different usage of the three prototypes was not analyzed. However, in another (ongoing) study we compared the different PDA versions and found that there were few differences between them regarding performance and user preference. This gives us confidence that our results are independent of the different PDA versions.

3.1.3 The Paper Chart

In a large regional university hospital in Norway where this study was conducted, "The Chart" (as it is widely named by its users) is a collection of important medical documents about the patient, gathered in a binder. It is used by the health workers as on-site documentation during patient visits [25]. The main document is an A4 size form containing the most important information about the patient, such as vital signs, prescribed medication, etc. In addition, the binder contains other documents such as recent test results or reports. In this study, domain experts, a physician and a nurse, were involved in creating a realistic paper chart for the fictitious patients used in the scenarios. However, it contained the same information that was available on the PDA.

3.1.4 Test Participants

Fourteen physicians participated in the study. They were all recruited from a large regional hospital and were paid for their participation. Their age ranged from 25 to 60 (mean = 41.4/SD = 11.7), with an even distribution of male and female. Their professional experience varied from young residents to senior head physicians.

Three sociology students at the graduate level and one student in the final year of a PhD in computer science acted as patients during the tests. Their age ranged from 26 to 47 (mean = 33.0/SD = 9.9). Three of the patient actors were female and one was male. They were paid for their participation.

3.1.5 Patient Scenario Objectives

Two patient scenarios were developed in cooperation with domain experts; a senior doctor working at the hospital and a PhD student previously employed as a nurse. The purpose of the patient scenarios was to 1) provide a realistic clinical situation, 2) employ the physicians' professional experience and practices, 3) reduce the scope of the dialogue in the consultation, 4) reduce variations in the outcome, and 5) make sure the physicians had at least one interaction with the PDA or paper chart during the visit, triggered by the patients' complaints and concerns. One of the scenarios is presented below.

> The patient is a 44-year-old woman. She is hospitalized with an acute episode of Crohn's disease for two days. The current treatment was started right after admission of the patient. It comprises 1) Prednisolon (Prednisolone), 20 mg, tablet, twice a day, and 2) Salazopyrin (Sulfasalazine), 500 mg, tablet, three times a day.
> During the ward round the patient discloses to the physician that she has developed an itching rash over her entire body. She remembers that she had a similar reaction to some antibiotic, but does not remember its name.

3.1.6 Test Order

A within-subject test design was chosen to limit the number of tests and test subjects. Thus, each physician tested all four user interfaces. The test order of the different user interfaces was rotated to control and reduce possible learning effects.

For each user interface the physician used, we alternated between two patient scenarios to reduce the number of patient actors needed. Pilot testing with physicians who were not part of the study revealed that they were able to play the scenario realistically despite repeating the scenarios.

3.1.7 Instructions to Physicians

As part of the preliminary briefing we explained that the motivation for the experiment was to "test a user interface for a medication module for an electronic patient record system". The real purpose was not revealed to prevent participant bias. Each physician was given a guided presentation of the laboratory and the associated control room. They were also presented to the general tasks they were to carry out during the tests. Since the purpose was not to find usability errors of the system as such, they were able to familiarize themselves with the prototypes prior to the experiment.

All the test subjects were encouraged to communicate and interact with the patient actors as they would have done with actual patients in real clinical situations.

3.1.8 Instructions for Patient Actors

Before the arrival of the physician, the patient actors were given detailed instructions on how to behave according to the patient scenarios and asked to memorize this. In addition, they were given the same reasons for the experiment as the physicians.

3.2 Test Procedure

At the beginning of each test, the patient actor was lying in the bed in the patient room. In the hallway the physician was reminded of the case description of the next patient case and the user interface that would be used. This was repeated for each new prototype and patient case, while the next patient actor was getting into position in the bed.

3.2.1 Physician Post-test Interview

Immediately after completing all tests, the physician was interviewed about his or her experience during the test and about mobile computing in hospitals in general. The interview was performed in the patient room and videotaped. The interviewee had the PDA and paper chart available during the interview. The interview guideline was semi-structured with some predefined questions.

The first part of the interview focused on the different information devices that were used. To facilitate discussion and to avoid misunderstandings, cards with symbolic pictures of the different prototypes were provided for reference. The physicians were asked to rank the information devices in a card sort exercise, where they ordered the provided cards by preference (ties between cards were not allowed).

The second part of the interview focused more on general and open questions about the physician's opinion on the 1) suitability of PDA for real life usage in hospitals, 2) impact of the information devices on the care situation, 3) potential distraction by the different information devices, and 4) their opinions on how the patients experienced PDA usage during the consultation. In addition, the physician was encouraged to raise other issues of personal concern in the context of the test.

After debriefing the physicians were asked to fill in a short questionnaire to provide data on job details, professional experience, personal data, and previous experience with computer and PDA usage. The questions about previous experience were multiple-choice where the physicians reported on how often they used handheld devices and computers privately and in their job (daily, weekly, monthly or less often). They were also asked about the realism of the scenario, and were given an opportunity for an informal concluding chat.

3.2.2 Patient Focus Group

Immediately after all 14 test sets, the patients were gathered in a focus group. It was conducted in the same room as the tests with the paper chart and PDA available. The interview guideline was semi-structured with two main topics: 1) their experiences as patient actors during the tests, and 2) differences in the doctors' behavior when using paper and PDA. The patients were allowed to discuss freely within each topic. The focus group session lasted for about 30 minutes.

3.3 Analysis

3.3.1 Interviews and Focus Group

Data from the physician interviews and patient focus group were fully transcribed verbatim. The transcriptions were imported into NVIVO 8 software for analyzing qualitative data. With this software the interview data were analyzed by inductively identifying text segments and marking them with thematic 'codes' that highlighted certain aspects of the data, using techniques from a grounded theory approach [26]. During this analysis, the meanings and definitions of each code were continuously updated as new aspects were revealed in the material. Using the software for qualitative data analysis, we generated reports sorted by code linking interview extracts from the interviews. On the basis of these reports we sorted out five main themes to answer the research questions.

3.3.2 Video Recordings

The video recordings were analyzed differently than the interviews. It has been shown that very detailed video analysis allows observers to analyze the fine details of the human conduct, tacit knowledge, and social interaction [27]. Such details are hard to capture through analyzing interview transcriptions, "shallow" video observations, or "live" field observations.

Videos from all the 56 patient visits were analyzed qualitatively and discussed by two observers with a particular focus on 1) use pattern of the information device, 2) signs of distractions and reduced doctor-patient dialog, such as less dialog, slurred speech, or absence of eye contact, and 3) patient and physician behavior and non-verbal communication. Moreover, video fragments from a set of patient visits were shown to two senior physicians and three senior sociologists with the purpose of assessing the realism of the ward round situations and the physician-patient dialog.

Particularly interesting video fragments were identified, based on themes emerging from the interview and video analysis. These short fragments were transcribed in great detail; speech and actions were mapped to the timeline of the video fragment, following the transcription method described in a previous article [27]. A set of the transcriptions was conceptualized into explanatory figures using screenshots from the video fragments (▶Figs. 4–7).

Fig. 4 The clinicians displayed different pattern of use for paper and PDA.

4. Results

In total, we analyzed video data from 56 simulated ward rounds, data from 14 physician interviews and questionnaires, and interview data from one patient focus group with four patients. Altogether, this analysis gave insight into the effects of PDA

Fig. 5 Adding (a), obtaining (b) or searching for information (c) with the paper chart. Actions are highly distinct and visible for the patient.

Fig. 6 Adding (a), obtaining (b) and searching for information (c) with the PDA. For the patient the actions appear identical.

Fig. 7 The paper chart supported non-verbal communication (a and b); the physicians invited patients to speak by tilting the chart slightly towards them (b). This was not found for PDA usage (c and d).

usage on the physicians' prescription work, their concerns about using it in point-of-care situations, and the effects on the patient-physician dialog.

The two senior physicians and three senior sociologists, who assessed the realism of the simulated ward rounds, considered the participants' behavior to be representative of real-world patient visits.

The questionnaire revealed that in general the doctors' experience with computers was very good. Nearly all used computers daily, both in their job and privately. Only one physician reported using computers privately on a weekly basis. Their experience with handheld computers, such as PDAs, was mainly very low. Only two of them used PDAs or other handheld computers daily in their job while the rest used it rarely or never. Privately, two physicians used a handheld computer daily, one weekly and the rest rarely or never.

4.1 The Physicians Used Paper and PDA Differently

The individual behavior in the ward round situation varied from clinician to clinician, both regarding medical reasoning and patient care. These variations mostly concerned the medications prescribed, eye contact and verbal empathy directed towards the patient. In particular, we observed differences related to how they used paper charts and the PDA.

4.1.1 Interviews

The physicians commented that paper charts required them to remember a considerable amount of information, such as medication names, medication dosages, and drug interactions between medications. In addition, they pointed to the lack of mechanisms to detect and prevent errors and drug interactions. They also found it challenging to correct or erase medication entries in the paper chart, due to the permanent nature of ink-based pens. The PDA, on the other hand, provided *cancel* and *undo* mechanisms, in addition to providing correct medication names and available dosages. The physicians also expected that the system would provide them with warnings about drug interactions.

4.1.2 Observations

The different attributes of paper chart and PDA seemed to affect the way the physicians worked. The physicians displayed different *patterns of use* for the paper chart and PDA. With the paper chart, we observed that they first reasoned out which drug to prescribe, and then wrote it down in the chart. On the handheld device the physicians tended to "surf around" more, by checking what possibilities were available before prescribing a drug. If physicians changed their mind during the interaction, they would cancel the prescription process and start over again with another drug (▶ Fig. 4). Thus, the use pattern when prescribing using the paper chart was influenced by the lack of information "in the world" and lack of error prevention and undo mechanisms.

4.2 The Physicians' Use of the PDA Caused Distractions and Influenced Physician-patient Communication

The interviews that followed the simulated ward rounds revealed that the physicians were worried about distractions caused by the use of the PDA. They also feared the distractions would have a negative effect on the patient experience. In addition, the focus group discussion showed that patients' communication with the physician was affected by use of the PDA. The video recordings revealed a reduced quality of the physician-patient dialog observed as less dialog, less eye contact, and more slurred speech. We also observed how some physicians tried to compensate for the distractions from the PDA by explaining to the patient what they were doing.

4.2.1 Interviews

In the interview data we found that the physicians had different opinions about the perceived distractions from the handheld device compared to the paper chart. Twenty-nine percent (four) of the physicians were concerned about increased distractions from using the PDA. Forty-three percent (six) of them were concerned about distractions while using the device, but expected the problem to be reduced with training and experience. Twenty-nine percent (four) were not concerned about the level of distraction from the handheld compared to paper chart.

The physician interviews revealed that half of the physicians believed that the patient would either not notice any difference due to the use of handhelds at point-of-care (5) or that they would have a positive experience (2). The remaining half (7) believed that the patient would have a negative experience of handhelds.

Some physicians were skeptical about any technology at the point-of-care because they believed it would have a negative effect on the physician-patient dialog. One said "the problem with technology (…) is if it takes too much attention from the clinician and draws attention away from the patient". Another expected the mobile system to be "more of a disturbance in the conversation than old-fashioned paper". He continued: "…very easy to get focused on your device and forget about the patient. It becomes a third party in the patient-doctor conversation." In addition, the physical appearance of the device concerned some physicians. They believed that patients would be skeptical if the PDA looked too much like the doctors' personal device.

Some of the physicians, who claimed to experience distractions, believed that with time and training, both they and the patients would become used to the device, consequently reducing distraction problems. As one physician put it: "This [PDA] was quite simple to use. If I used it for weeks or months, it would be as simple as the [paper] chart."

Others found no differences in distractions between the paper chart and PDA. They considered both as tools to which they had to relate. One physician said: "It is not different than having a paper record. Either you look at the paper or you look at the screen."

Some physicians expected that the physical shape and design of the handheld would worry the patients. The paper charts are red, have a front page marked with the patients' name and birth date, and are often carried around by the health workers in the hospital. The handheld device, however, looks like the physicians' own personal device. The physicians expected the patients to dislike this as the tool might appear to be their personal device, but used to collect and add clinical information. To prevent this, they suggested that the devices should not look like their personal mobile phones or PDAs, but "rather look like a hospital tool".

4.2.2 Observations

While reading or writing in the paper chart, most physicians were able to maintain more fluent dialog and sporadic eye contact with the patient, compared to their behavior when using the PDA. Only a few physicians were able to maintain the physician-patient dialog using the PDA equally well as when using the paper chart.

In some of the ward rounds we observed that physicians experienced considerable distractions from the handheld device. We observed them speaking slower, more slurred, or being completely silent when prescribing medications with the PDA-based prototypes. When the physician experienced such distractions from the device we observed that the patients avoided disturbing him/her. For several doctors, this had a negative influence on the physician-patient conversation. The tendency was not so frequent with paper chart.

On the other hand, observations also showed that a few physicians were able to use the PDA and paper equally well. They were able to prescribe medication and simultaneously attend to the patients or respond to their questions and concerns.

Some physicians tried to make the ward round with the PDA as transparent and non-threatening as possible by notifying the patient about "this new device" and explaining its benefits.

4.2.3 Patient Focus Group

The findings from the observations and interviews were supported by the patient focus group. When the patients were asked about their opinions after all the tests, they claimed to experience "more embarrassing silence" during the simulated patient visits where the physicians used the PDA. This silence hindered them from asking questions because they did not want to disturb the physician. They found it easier to ask questions when the physician used the paper chart. The patients also perceived that the physicians asked more questions, and was more confident and comfortable using paper. However, they did not notice any significant differences in how fast they worked with PDA and paper chart.

4.3 With the PDA, Patients Were Less Aware of What the Physician Was Doing

While the physicians' actions were highly transparent to the patient when paper was used, PDA usage adversely affected action transparency.

4.3.1 Interviews

Physicians using the PDA described the device as more "mystical" than the paper chart because the patients could not see what they did on it. Although the paper chart normally is not available for patients, some physicians described certain patients that often want, and are allowed to, have a look at their own chart. According to these physicians, the paper chart supported this form of information-sharing with the patient better than the PDA, since all the important information was available on one sheet instead of distributed between several screens.

4.3.2 Patient Focus Group

The patient focus group discussion revealed that patients found it easier to ask questions when the paper chart was used, because they were more aware of what the physicians were doing.

4.3.3 Observations

The above findings were supported by the ward round observations. We observed that the physicians' actions were more visible and transparent to the patient with the paper chart than the handheld system. When they used the paper chart it was clearer to the patient whether the physician was adding (writing), obtaining (reading) or searching for information (turning pages) (▶Fig. 5.). When they used the PDA (▶Fig. 6.), all their actions appeared equal (pointing or tapping on the touch screen).

4.4 Physicians Were More Confident and Comfortable with Paper, but Preferred Using PDA

Despite the concerns they had about using PDAs in consultations with the patients, physicians saw many benefits of handheld devices.

4.4.1 Interviews

Most physicians were more confident and comfortable with paper usage. They found paper quick and easy to use, as they had years of previous experience with it. Use of the paper chart was also easier to share with colleagues. It offered better information overview, and it gave them freedom to write without having to relate to drop down boxes, text fields and other system restrictions. In addition, there was no chance of system crashes and malfunctions when using charts.

However, despite sparse experience with handhelds and only little training on the medication system used, most physicians preferred the PDA-based prototypes when asked to rank them against paper. The main factors in favor of PDAs were that paper lacked error prevention, had no undo mechanism, and required them to remember medication names and dosages (see Section 3.1). It also implied more work afterwards when medications had to be registered again in the electronic patient record.

4.4.2 Patient Focus Group

The patients also perceived physicians as being more confident and comfortable when using the paper chart. They did not notice whether the doctor worked faster with the paper chart or the handheld device.

For the patients, who could not see the content of the two information devices, the physicians appeared to have more information available on the paper chart than the PDA, even if the amount of information was exactly the same.

The patients also commented that they would prefer the physicians using the PDA if they were comfortable using it. The main reason was its physical size; they appreciated that it occupied less space between the physician and the patient and that it could be stowed away in the physician's pocket. However, they also commented that the most important factor should be the contact the physician gets with them as patients, regardless of tool and technology.

4.4.3 Observations

Less slurred speech, more eye contact with the patient, and less embarrassing silence indicated that physicians were more confident and comfortable using paper (see Section 4.2). However, one factor that may explain the preference for PDA usage was that the PDA was easier to stow away than the paper chart. In addition, the PDA was easier to hold while adding information. Some physicians experienced problems when writing in the chart; their arm got tired and they were forced to change the way they held the chart several times, or they were distracted by their ID card, which was placed on a string around the neck and obstructing their writing.

4.5 The Paper Chart, and to a Lesser Degree the PDA, Was Used for Non-verbal Communication

We observed that the paper chart was used more frequently for non-verbal communication than the PDA. Due to the tacit nature of non-verbal communication we found no support, nor discrepancies, for these observations in the interview data.

4.5.1 Observations

During the consultation several physicians tilted the position of the chart towards the patient when asking questions (▶Fig. 7a and 7b), giving the patient a non-verbal invitation to speak. Also, when the medication change was performed and the consultation was moving towards the end, many physicians firmly closed the chart before asking the patient if they had any other questions or issues they would like to discuss. This non-verbal hint was given to the patient to inform and underline that the consultation was coming to an end.

The PDA did not support this non-verbal communication to the same extent (▶Figs. 7c and 7d), although some physicians firmly placed the stylus back in the PDA when the consultation was ending.

5. Discussion

In this paper we have presented the results from a usability evaluation of simple, PDA-based prototypes of a hospital information system and a paper-based medical chart. The results from this evaluation showed that physicians used PDA and paper differently; the usage was influenced by the lack of information "in the world" and the lack of error prevention and undo mechanisms on paper. However, the physicians were worried that PDA usage would cause distractions and have a negative effect on the doctor-patient dialog, something we found evidence for in both the observations and patient focus group. We also found that the physicians' actions were less transparent to the patient when using a PDA. Moreover, the PDA was more disruptive for non-verbal communication. Despite being more confident with and accustomed to the paper chart, the physicians preferred using the PDA because it reduced the need to recall information by providing concrete alternatives in the user interface.

By creating an experimental setting that allowed healthcare professionals to test the prototype in a highly realistic scenario, we obtained a rich set of observational data. In addition, we interviewed the test persons immediately after the experiments, thereby collecting data on the experiences that the use of the prototype had aroused in them. By including the testing of the traditional paper-based patient chart we could compare and contrast the pros and cons of electronic and paper media. To our knowledge, this study is one of the first to conduct a head-to-head comparison on the effects of the use of a paper chart vs. a PDA on the physician-patient dialog in a ward round situation.

One of the principal findings, which can explain and supplement the results found by Houston et al. [9] and McAlearney et al. [15], is that physicians have reservations about using PDAs in front of the patient, because the device draws the physician's attention away from the dialog with the patient. The ward round situation is a meeting between the patient and a physician and the principal function of an information system is to assist the communication in that situation. However, there is a risk that the user interface can occupy the users' attention. Users might get distracted by the PDA because they find it has more awkward input, lower readability, poorer overview, increased number of focus shifts between the patient and the device, increased fiddling with device, more functionality tempting the physicians to rely more on the device, and more usability problems. The distractions from the PDA, and its poor support for action transparency and non-verbal communication, made it difficult to maintain a continuous dialog and eye contact with the patient. Viewed in the light of the findings by Ilie et al. [12], who used the Technology Acceptance Model [11] and found that information-accessibility is one critical factor for technology acceptance and usage, our findings suggest that the ability of the technology to support a parallel task – communicating with the patient – is also one of the important factors for the users' acceptance of the technology. Having good access to an information source does not suffice.

The medication system was deliberately made as simple and user-friendly as possible by reducing the functionality and basing the user interface design on principles reducing cognitive load. The users' comments on how easy it was to operate, verified that the system was user-friendly. However, when they tested the system in a ward round situation and in the presence of a patient actor, we observed that even this simple system drew their attention away from the patient and the dialog. In accordance with this, the patient actors reported poorer dialog with the physician when a PDA was used. A fully developed system must have a much wider set of features and therefore more complex screens or navigation structure. Extrapolating the findings of this study, we conclude that the problem of distraction probably is of critical concern in the design of small-screen user interfaces for healthcare information systems.

Another finding, which supports Dahl et al. [14], was that the paper chart's affordances were of high value for the physician-patient interaction. These qualities were hard to replicate with a PDA. Users of the paper chart literally have a lifetime of experience with its interaction style (pen and paper). Compared to the PDA, it is easy to do text input on paper (just write), it has excellent support for co-located asynchronous collaboration (simply show it to a colleague), and it has a large 14-inch work space with excellent contrast and resolution (>600 dpi) that can be positioned at a perfect reading distance (better readability on paper). Moreover, it has unlimited battery capacity (does not use power), it is lightweight (weighs less than a PDA), and it is easy to navigate in and to see where you are (just turn the pages).

One particularly valuable affordance of the paper chart was the possibility of using the artifact for non-verbal communication with the patient. For instance, the physicians invited patients to speak by tilting the chart slightly towards them. Likewise, the test physicians signaled that the encounter was coming to an end by closing the paper chart. This affordance was hard to replicate with a PDA. We also observed that information retrieval and input were more transparent for the patient when the doctor used the paper chart. In general, the PDA created a more fragmented communication environment compared with the paper chart. When using the PDA, the patients were less aware of what the physician was doing, and this had a negative impact on the quality of the patient-physician dialog.

On the other hand, and as the physicians themselves pointed out, they will, with years of training and experience, learn how to use the device efficiently without letting it become a third party in communication with the patients. In addition, the benefits of the device, such as its ability to display "knowledge in the world" and the fact that it can be stowed away when not in use, can exceed the benefits of the paper chart, thus becoming a better tool than its paper-based counterpart.

Supplementing the video-recorded observations by carrying out interviews and having the physicians fill out questionnaires immediately after the experiments allowed us to develop a more complete picture of what happened during the experiments. By performing the interviews immediately after the experiments we captured the reflections and opinions of the physicians while their PDA and paper experiences still were fresh in mind. Another meta-observation is that the physicians rarely commented on concerns of a specific solution until after having hands-on experiences with other alternatives. Thus, by exposing the physicians to multiple PDA interaction designs, we unveiled more concerns. The cards and the card ranking exercise also helped the physicians remember the different alternatives and led to more focused discussions. Likewise, having the devices and paper chart available during the interview helped them reconsider their thoughts. All in all, we believe this multi-perspective, multi-method approach gives more valid results compared to studies that rely on the application of one method alone (i.e. either focus groups, interviews, surveys or usability walk-throughs).

5.1 Limitations

A limitation of this study is that the medication system used in the simulated ward round did not reflect the complexity of real-life scenarios. The scenarios and patient cases had to be adapted to match the functionality that the prototype offered. It may be argued that the functionality was too sparse, and the user interface too simple. The fact that only a few physicians commented on the simplicity of the system functionality is an indication that it delivered what they expected from the scenario. On the other hand, since the scenario was simulated, the effects of the physicians' actions did not have real-life consequences. This might have influenced their behavior.

The lack of real patients and the low number of patient actors is another limitation of the study. In addition, the 'patients' did not have a medical problem, thus they did not worry about the consequences. This may have affected the realism of the interaction between the patient and physician. Because of this, the results can only be used as an indication of patient experience and a direction for further work on how persons in care-receiving situations might perceive the clinicians' use of handhelds compared to paper charts.

The fact that the physical setting and scenarios were not real but invented by the researchers might be considered a third limitation to this study. While real-life health care means time pressure, interruptions, risk of medical errors, decisions influencing the patients' lives, interactions with patients' fears and hopes, and need to communicate with colleagues, none of these elements were replicated in the simulated ward rounds. However, the group analyzing the realism of the consultations expressed that the physicians, in most cases, were able to act and respond realistically to the patients' complaints. In addition, the participating physicians confirmed after the tests that the scenarios and physical setting were sufficiently realistic for them to behave naturally.

Given the variation in the tests regarding medical treatment and care, one may question the reliability and generalizability of the study. However, several studies show that doctors' behavior varies – also in the real world [28].

6. Conclusion

Despite the many benefits, PDA usage at the point-of-care comes with the increased risk of distractions, reduced ability to communicate non-verbally to the patient, and poor action transparency, which makes it harder for the patient to see what is going on. This can cause a negative patient experience.

Designers of point-of-care systems need to be aware of, and address, the problems with PDAs and learn from the affordances of paper charts. Based on the findings we present some implications for the design of handheld point-of-care systems that might help reduce a few of the disadvantages of bedside computing.

- **Pocket-sized.** Point-of-care systems should be pocket-sized, allowing the physician to stow it away when not using it, thus being free to fully attend to the patient. It will prevent the temptation of unnecessary information retrieval and it will avoid the PDA unintentionally becoming a third party in the doctor-patient conversation.
- **Keep the user interface attention-easy.** Create a simple and attention-easy user interface that allows the user to focus mainly on the patient. One solution that can reduce the physicians' attentional demands when using PDAs at the bedside is to design a PDA which effectively supports the fastest and easiest tasks and at the same time allows for partial completion of the more complex tasks. This allows the physician to perform the tasks that can quickly be completed at the point-of-care, while the more complex tasks can be started at the bedside and completed in the office. This will prevent the physicians from getting absorbed by endless forms and lengthy drop-down lists at the point-of-care.
- **Use a hospital standard.** To make the patient confident that the device is not the physician's personal tool, care should be taken to design the device to look like hospital equipment (white might do, or a logo on it?).
- **Support non-verbal communication:** With training and experience the doctors will learn how to communicate non-verbally with the handheld device. However, the physical shape, weight, size, and the way it can be held, will help. Therefore, the device should be designed to support non-verbal communication.

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Paper 6:
Important usability factors for point-of-care systems

Authors: Ole Andreas Alsos and Benjamin Dabelow

Full title: A Comparative Evaluation Study of Basic Interaction Techniques for PDAs in Point-Of-Care Situations

Published in: Proceedings of Pervasive Health 2010, IEEE

Is not included due to copyright

Paper 7:
Secondary user experience

Authors: Ole Andreas Alsos and Dag Svanæs

Full title: Designing for the Secondary User Experience.

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Paper 8:
Card Ranking

Authors: Ole Andreas Alsos and Yngve Dahl

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Ranking for Reflection: The Application and Added Value of Picture Cards in Comparative Usability Testing

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Abstract: Comparative usability evaluations and preference rankings are useful in terms of informing further system design. However, for test participants such evaluations can be challenging since they must remember and distinguish between different design solutions. This paper describes the application and added value of using picture cards and card ranking exercises in comparative usability evaluations. Users discuss and rank design solutions they have tested by placing corresponding symbolic cards in preferred order. The method is non-intrusive, cheap and efficient. In addition to provide quantitative and qualitative data on the users' preferences, the technique helps users to remember the design solutions, encourages user reflection, and simplifies the facilitator's and data analyst's job.

Keywords: Card sort, card ranking, preference ranking, comparative usability evaluation, user-centered design.

1. Introduction

One of the main objectives of usability evaluations of ICT is to get participants to reflect on usage. This is particularly the case for early concept evaluations, where the aim is to collect data that can help inform further system design. However, in the context of comparative usability evaluations, where test subject try out multiple alternative solutions, it can be challenging to collect user reflections using traditional techniques, such as talk-aloud [1] during the evaluation, questionnaires [2], or interviews [3] after the evaluation. Below we summarize some key challenges of these techniques:

- Talk aloud works poorly when tasks or scenarios require participants to interact or communicate with other actors that play a role in the scenario; their attention is directed towards these actors, not the moderator [4].
- Questionnaires and interviews do not support the users memory. Because of users' limited short time memory and the need for test subjects to remember and distinguish between all the design alternatives, the techniques are cognitively demanding (especially when the number of tested solutions is high).

- It can be demanding for test moderators to connect users' feedback to the right solution alternative, particularly if the differences are minor and subtle.
- Questionnaires are predetermined and have poor support for follow-up questions from an interviewer.
- The usability evaluation and the interview use different cognitive modalities. While test subjects experience visual stimuli when using the design alternatives, interviews traditionally engage the auditory modality.

The food industry has found an interesting solution to these challenges. In comparative studies of taste with children, researchers use picture cards representing food [5]. A similar approach is taken in the studies described in this paper. To provide a cognitive aid for test participants and facilitators during post-test interviews, we have found it useful to hand out of picture cards illustrating the various design solutions. In this paper, we illustrate how picture cards can form a cost effective and useful tool for preference ranking and reflection for test subjects. We also demonstrate how picture card rankings are applicable for both quantitative and qualitative data collection in usability testing.

Although similar techniques may have been previously used in HCI-research, we have not found any studies explicitly describing such method.

2. The Card Ranking Technique

Various techniques involving cards have been applied in the design of computer systems, and the advantages are well reported [6]. The basic idea behind these techniques is to allow participants to sort cards that represent objects, concepts, or terms into groups [7]. Card sorts are often used to provide user input for web page information architecture [8] or used as a cognitive requirements elicitation technique [9]. The main drawbacks of the card sorting technique are that both the preparation, execution and the subsequent data analysis can be relatively time consuming [10]. On the other hand, usability professionals claim the technique to be simple, cheap and fast [11].

We have used a variant of the card sort technique where users, after trying out different design solutions, sort picture cards representing the solutions in preferred order. The cards are used during the post-test interview, where the card ranking exercise is performed as part of it. The current technique has been applied in, and evolved through a number of comparative usability evaluations of health information systems [12-15]. In each of these studies we have compared and evaluated three to eight design solutions. The number of test subjects has ranged from five to fourteen.

2.1 Card design

For each study, we created cards representing the design solution to be tested. Each card illustrated one specific solution. The cards were designed using screen shots, simple concept figures, or photos so that the users were able to easily recognize the different designs, without

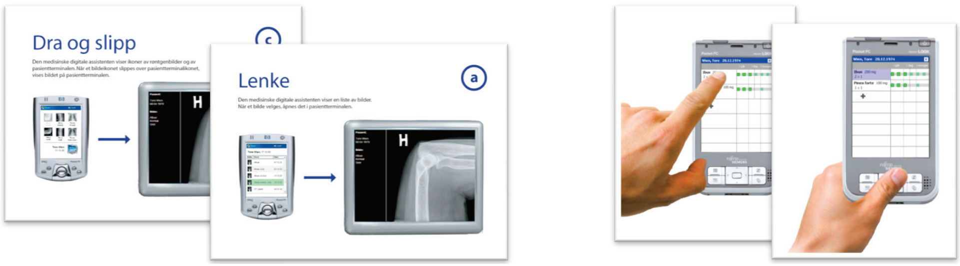

Figure 1. Examples from two sets of cards used in two usability studies. Each card represents a specific design solution. The cards to the left represent 2 of 8 interaction techniques (drag-and-drop and WIMP) for using handhelds and bedside patient terminals together. The cards to the right represent 2 of 4 interaction techniques for a medication system used bedside in hospitals.

complex explanations or state charts. In some evaluations, identification marks were printed on the cards to support coding of data and analysis. Examples of some of the picture cards we have used are shown in Figure 1.

2.2 Procedure

We performed usability evaluations where each user tested a set of alternative design solutions for a specific scenario. To acquire the users' immediate feedback on the solutions, a short interview was performed after each design alternative had been tested.

After the test participant had evaluated all the design solutions, we performed a concluding interview where we presented the picture cards to him/her. The cards were presented one at a time in the same order as the corresponding design solutions had been tested. For each

Figure 2. After testing a number of design solutions (*left*), the users was asked to comment on each solution and sort corresponding picture cards in preferred order (*middle*). The final sort order represented the users' preferences (*right*).

presented picture card the test subject was asked to comment the illustrated design solution.

After all the design solutions had been discussed, we placed the cards face up in random order on a table. We then asked the users to rank the cards in preferred order, and to state the primary reasons for their decisions. The exercise was video recorded for subsequent analysis. Figure 2 shows the general procedure of the described card ranking exercise.

3. The added value of Cards Ranking Exercises

The added value of card ranking exercises in comparative usability testing is summarized below.

3.1 User reflection

We found that card ranking was an effective catalyst for user reflection and for understanding qualitative aspects of the designs. It provoked second thought, re-evaluation, and offered the possibility for test participants to compare strengths and weaknesses of the various solutions. Test subjects used the cards actively to point at and discuss aspects of the various designs. Comments were highly specific to the solutions illustrated on the different cards.

We found that the arguments used when ranking the solutions in a particular order was important indicators of what the users found to be important factors for the overall usability of the system. In Figure 3, we present an example of factors influencing the users preference. The factors were taken directly from arguments that users discussed in the card ranking exercise.

We found the card ranking exercise to be particularly reflective when we encouraged test subjects to collaborate on the task [12]. In these cases usability factors of the design solutions were discussed in more detail and from the perspective of more actors. Consequently, it resulted in a more time-consuming card ranking session.

Based on our experiences from comparative evaluations with and without the card ranking technique, test participants find it easier to discuss and reflect on picture cards representing a design solution rather than their experiences of the solutions recalled from the memory.

3.2 Concrete tools of reference

We observed that the cards supported the test participants' memory by providing "knowledge in the world", i.e., concrete reference tools that help them remember and distinguish between the various design solutions. Moreover, the cards allowed tests participants to recognize and literarily "point" at problems or advantages, instead of having to recall them from their memory.

We consider it crucial that the picture cards are carefully designed so that they effectively and simplistically communicate the distinct properties of each illustrated solution.

Factors influencing the users' preference	Styl.	Fing.	Butt.	Pa
Reliability (software malfunctions)	-	-	-	+
Information readability and overview	-	-	-	+
Error prevention and decision support	+	+	+	-
Patient experience	-	-	-	+
Need for additional tool (pen/stylus)	-	+	+	-
Mapping between input/output	+	+	-	+
Physical size	+	+	+	-
Accuracy	+	-	+	+
One handed usage	-	+	-	-
Efficiency	+	+	-	+
Physical feedback	-	-	+	+
Feeling of security	-	-	+	+
Flexible usage	-	-	-	+
Redundant registration	+	+	+	

Figure 3. The card ranking exercise revealed factors important for the overall usability of the system and how each design solution accommodated these factors. This example is from a further analysis of [16].

3.3 Facilitating post-test interviews and data analysis

In addition to acting as memory aids for test subjects, picture cards were also helpful in terms of facilitating concluding interviews with test participants. For the facilitator the picture cards were especially useful for focusing and guiding the discussion, and promoting systematic and solution specific feedback from the participants. By referring back to the cards, the facilitator brought the discussion back "on track" when the test participants were heading off-topic.

During post-test interviews the pictures cards acted as common references between the facilitator and the test subject (or between test participants as shown in Figure 2). This helped the different parties understand which design solution comments and questions were related to and reduced confusion. It also simplified the video data analysis, since the analyst could see and interpret what design and design aspects the participant referred to.

The arguments given by test participants during the card ranking exercise were analyzed to identify categories of factors affecting usability. For some studies, data was coded into software for qualitative data analysis and analyzed using an approach inspired by grounded theory [16].

3.4 Quantitative data on the users' preferences

The card ranking exercise generated quantitative data on users' preferences. These data were used as a statistical indicator for which designs or design aspects that were most preferred by the users and therefore appropriate for further development.

For each usability test, the card order was coded from 1 (least preferred) to *n* (most preferred), and the median card rank, average and total card score was calculated for each design solution. These resulting scores gave an indication of users' preference, but more detailed analysis was required to check for statistical significance.

A Friedman test on the data set revealed if there were any significant rank differences between the design solutions. If this test were positive, we performed a Mann-Whitney test, which tested the significance of the rank difference for each pair of design solutions, giving a total of $\sum(n - 1)$ tests.

4. Discussion

The card ranking technique was developed for comparative usability evaluations where the talk-aloud technique was inappropriate, and where high cognitive demands was put on the user, who had to remember and differentiate between a number of alternative solutions. The cards acted as cognitive reminders and concrete reference points, both for the participants and for the facilitator.

Card ranking is a low cost technique. Since the card ranking technique is used in parallel with the post-test interview, the time cost is limited to designing and printing the cards. In addition, the technique also helps focus the interview. The solutions, represented by tangible cards, are the topic of the discussion, and the participants and facilitator are constantly reminded about that. Moreover, the technique is non-intrusive; the cards are used as the focal point of the post-test interview, but can be ignored if the circumstances require it.

When increasing the number of solutions being evaluated, the cognitive load on the test user is likely to increase. A higher number of candidate solutions will therefore probably increase the applicability of card ranking exercises.

Using the ranking data as a statistical indicator of preference, as described above, can be problematic. It only provides quantitative data on preference of one solution over another – it fails to quantify *how much* better the solution is rated. In addition, given the effect of sample size on statistical significance, we deduce that a large number of test subjects are needed to give more reliable ranking data. Therefore we consider the qualitative dimension to be most important; the arguments used by the users when ranking the solutions can provide valuable insight into what usability factors are important for the participants.

Instead of considering card ranking as a card sort variant, we rather regard it primarily as a qualitative technique helpful during comparative evaluations. The technique triggers user reflection, helps the user and test facilitator focus the interview, and supports the analysis of data.

5. Conclusions

Comparative usability evaluations are useful in terms of informing further system design. However, such evaluations are challenging since they put an added cognitive burden on test participants.

Ranking exercises with picture cards illustrating design solutions is a non-intrusive, cheap, and efficient technique that we have found highly useful in the context of comparative usability testing. In addition to providing quantitative data on users' preferences, the technique helps users distinguish between design solutions, promotes user reflection, aids the test subjects' memory and act as a concrete and common reference tool for both test subjects and facilitator during post-test interviews. It also simplifies the post-test data analysis.

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1. Alsos, O. A., Dabelow, B., Faxvaag, A. (2010). *Doctors' concerns of PDAs in the ward round situation: Lessons from a formative evaluation study.* Methods of Information in Medicine, 50(2), 2011.

2. Alsos, O. A., Dabelow, B. (2010). *A Comparative Evaluation Study of Basic Interaction Techniques for PDAs in Point-Of-Care Situations.* Proceedings of Pervasive Health 2010, IEEE.

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4. Alsos, O. A., Dahl, Y. (2008). *Ranking for Reflection: The Application and Added Value of Picture Cards in Comparative Usability Testing.* Presented at Yggdrasil 2008, available at [http://bit.ly/paper8]

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