Electronic Whiteboards in Emergency Medicine

Studies of Implementation Processes and User Interface Design Evaluations

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PhD Thesis

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Electronic Whiteboards in Emergency Medicine: Studies of implementation processes and user interface design evaluations

Academic supervisor: Morten Hertzum

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Abstract

Through a series of studies I have investigated how the user interface design and implementation approaches of an Electronic Whiteboard system has affected the clinicians' perceptions and usage of the system at four Emergency Departments in Region Zealand, one of five healthcare regions in Denmark. The performed studies include one systematic literature review, two controlled experiments, two qualitative usability evaluations and two qualitative field observation and interview studies. In this cover paper, I present and discuss my methodological choices and provide descriptions of the performed studies in the form of extended abstracts. I then discuss and relate the findings of the different studies and discuss these against a range of previously published literature.

The overall conclusions of my research can be divided according to relevance between the healthcare informatics research community and practitioners interested in the results of my studies. For the healthcare informatics research community the main relevance of my research lies mainly in the theoretical findings and discussion presented in the adjoining papers and this cover paper. This includes discussions regarding the need for more extensive experimentation with the technical and organizational aspects of healthcare information systems and discussions regarding a *co-realisation* approach to the design and implementation of these systems. The findings of the performed literature review present a number of findings relevant for researchers interested in issues specifically related to Electronic Whiteboard systems and how these systems affect Emergency Departments. Other research related findings include the general findings of the usability evaluations performed and a call for more focus on earlier and more thorough evaluations. Finally, the methods in a number of the studies could be of interest for researchers interested in unobtrusive usability evaluation methods.

For practitioners interested in my research the main relevance is found in the more concrete results of my research. This includes the discussions of the design and implementation processes at the four Emergency Departments and how the clinicians have perceived these processes. Also included is the suggested *co-realisation* inspired approach for future endeavours of designing and implementing the Electronic Whiteboard system as well as the discussions of experimenting with the technical and organizational aspects of such systems. The detailed results of the usability evaluations and controlled experiments are also of relevance to practitioners and can be employed directly with relative ease.

Dansk resumé

Igennem en række studier har jeg undersøgt, hvordan designet af brugergrænsefladen og de fulgte implementeringstilgange for et Elektronisk Whiteboard system har påvirket klinikernes opfattelse og brug af systemet ved de fire Akutafdelinger i Region Sjælland. De gennemførte studier omfatter et systematisk litteraturstudie, to kontrollerede eksperimenter, to kvalitative usability-evalueringer samt to kvalitative observations- og interviewstudier. I denne sammenfatning vil jeg præsentere samt diskutere mine metodologiske valg og beskrive de gennemførte studier i form af udvidede resuméer. Derefter diskuterer og relaterer jeg de forskellige studier til hinanden og diskuterer disse mod en række af tidligere publiceret litteratur.

De overordnede konklusioner af min forskning kan opdeles i forhold til relevans i mellem et forskningsområde orienteret omkring sundhedsinformatik og praktikere med interesse for designet og implementeringen af sundhedsinformatiksystemer fx udviklervirksomheder og sundhedsautoriteter. For det forskningsorienterede område ligger relevansen af min forskning hovedsageligt i de teoretiske resultater og diskussioner, der præsenteres i denne sammenfatning og de tilhørende artikler. Dette inkluderer diskussioner angående behovet for mere omfattende eksperimenter med de tekniske og organisatoriske aspekter af sundhedsinformatiksystemer samt diskussioner angående en *co-realisation* tilgang til designet og implementeringen af sådanne systemer. Resultaterne af det gennemførte litteraturstudie sammenfatter en række resultater med relevans for forskere, der er specifikt interesserede i Elektroniske Whiteboard systemer og hvordan disse systemer påvirker Akutafdelinger. Andre resultater med relevans for det forskningsorienterede område omfatter de generelle resultater fra de gennemførte usability-evalueringer samt en opfordring til tidligere og grundigere evaluering. Endelig kunne de metoder, der er blevet anvendt i et par af studierne, være relevante for forskere med interesse i usability-evalueringsmetoder, der ikke virke påtrængende overfor brugerne.

For praktikerne ligger relevansen af min forskning hovedsageligt i de mere konkrete resultater. Dette inkluderer diskussioner af design- og implementeringstilgangene ved de fire Akutafdelinger og hvordan klinikerne har opfattet disse processer. Derudover inkluderer det også den foreslåede *co-realisation* inspirerede tilgang for fremtidige design- og implementeringsprocesser for Elektroniske Whiteboard systemer samt diskussioner angående eksperimenter med de tekniske og organisatoriske aspekter af sådanne systemer. De detaljerede resultater af de gennemførte usability-evaluering og kontrollerede forsøg er også relevante for praktikere og kan umiddelbart anvendes med relativ lethed.

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1 Introduction

This PhD thesis describes and discusses the results of my research on Electronic Whiteboards used for communication and workflow coordination in Emergency Departments. This research was conducted as part of project "Clinical Overview" – a region wide research and development project in the Danish healthcare region of Zealand.

The thesis is structured as a paper collection with this cover paper acting as the summary for the adjoining papers. This cover paper contains an introductory section where the research project, the Electronic Whiteboard system and the Emergency Departments are described. This section also introduces my overall research question and associated sub questions. Following the introductory section, I present a review of previously published research related to my research question. After this I present and discuss my methodological choices regarding research strategy and design as well as data collection and data analysis methods. This is followed by a presentation of the adjoining papers in the form of an extended abstract for each paper. In the discussion section, I position my research and discuss my findings in relation to the existing literature. Finally, I present my conclusions and outline the answers to my research questions.

1.1 Emergency Departments

Since all of my research and empirical work has been carried out in the context of the Emergency Departments in Region Zealand I feel that it is pertinent to briefly describe the work and the working practices of these departments. The Emergency Departments are, in their current form, relatively new entities in Region Zealand and in Denmark in general. Based on the Danish Health and Medicines Authority's (DHMA) recommendations for improved acute care (DHMA, 2007), Region Zealand and the other healthcare regions of Denmark launched a national project in 2009 aimed at developing and implementing Joint Emergency Departments at selected hospitals throughout the five regions. In the 2007 report from DHMA a Joint Emergency Department is defined as follows:

> *"… A common physical location at a hospital residing on one cadastre to which acute sick or injured patients can be referred or brought in and where there is an option for diagnostics and treatment with acute medical aid from multiple specialties regardless of whether treatment can be performed in the emergency room or requires hospitalisation"* – (DHMA, 2007 pp. 30)

In general the Emergency Departments provide a single point of entry for all patients except very well defined patient groups e.g. parturient women. Patients received at the Emergency Department (ED) are triaged, diagnosed and initially treated. Then, depending on the patients' health state they are either discharged or admitted to one of the hospital's specialty wards e.g. medical or surgical.

In Region Zealand four hospitals were selected to host such Joint Emergency Departments. In 2009 the development and implementation of these departments was initiated and while one department still operates in temporary physical premises the other three have become fully operational (Region

Zealand, 2011). In establishing the EDs several departments at each hospital were combined to form the Joint Emergency Departments e.g. emergency rooms, receiving departments etc. This ultimately led to an increase in the number and diversity of patients admitted, which has resulted in an often hectic and somewhat chaotic working environment at the EDs. This increased the need for the clinicians at the EDs to be able to gain and retain an overview of the patients, staff members and the state of the ED in order to efficiently coordinate workflow and communicate internally.

1.2 Dry-erase whiteboards

To this end the clinicians initially adopted the manual coordination and communication systems used in the departments from which the EDs were formed. These systems consisted of dry-erase whiteboards augmented with a matrix-like structure used to display patient specific information such as name, age, medical problem, attending nurse/physician and future plans for the patient. Previous research has shown that dry-erase whiteboards such as these are ubiquitous in various hospital departments and are vital for efficient and effective work practices at EDs and hospital departments in general (Bardram & Bossen, 2005; Bisantz et al., 2010; Bjørn & Hertzum, 2011; Chaboyer et al., 2009; Wears & Perry, 2007; Wears et al., 2007b; Xiao et al., 2001). Other strands of research have shown that clinicians at the EDs regard these dry-erase whiteboards as being very important for their work and pivotal for the collaboration between clinicians (Hertzum & Simonsen, 2010). Figure 1 shows a picture of the previously used dry-erase whiteboards from one of Region Zealands EDs.

Figure 1. The previously used dry-erase whiteboard from one of the Emergency Departments in Region Zealand

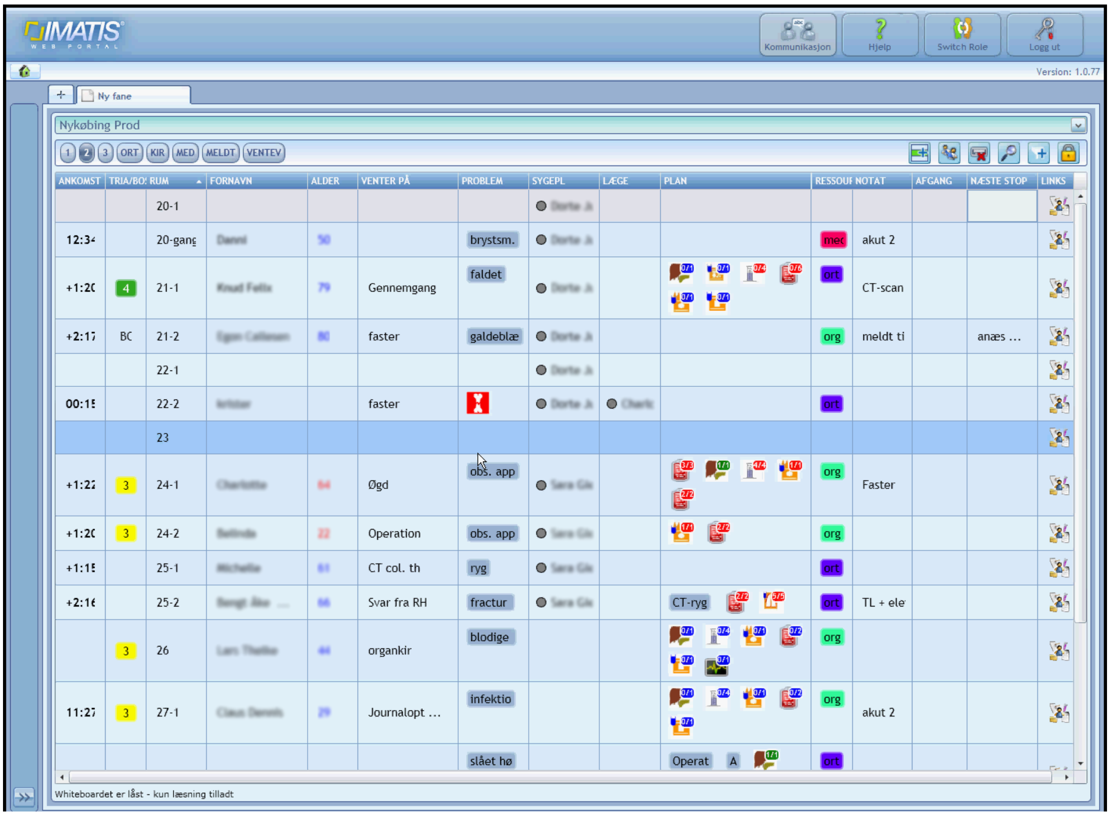

Figure 2. The electronic whiteboard system at one of Region Zealand's Emergency Departments

1.3 Electronic whiteboards

However, as the number of patients admitted to the EDs on a daily basis has increased and the Danish government's focus on documentation and patient safety has been strengthened electronic alternatives have started to replace the dry-erase whiteboards. These alternatives are often termed Electronic Whiteboards (EW) and provide a number of advantages over the dry-erase whiteboards in terms of storing and retrieving patient information, integration with other clinical IT systems, distributed access and consistent data entry. On an international scale EW systems have been used for some years and have been the focus of research in a range of studies (Abujudeh et al., 2010; Aronsky et al., 2008; Bisantz et al., 2010; Boger, 2003; Fairbanks et al. 2008, France et al., 2005; Potter, 2005; Wears et al., 2003; Wong et al., 2009; Zimmerman & Clinton, 1995). On a national level EW systems have been introduced recently at Danish hospitals. With the formation of the cross regional healthcare IT collaboration (RSI) in 2010 the introduction of EW systems at Joint Emergency Departments was presented as one of the goals for this collaboration (Danish Regions, 2010) and was thereby elevated to a matter of national interest. It is with this background that Region Zealand initiated the "Clinical Overview" research project aimed at developing and implementing a common EW system for the four EDs in the healthcare region. And it is within the context of this project and the four EDs that I have conducted my research and empirical work. Figure 2 shows a screen shot of the EW system's user interface as it has been configured at one of the EDs in Region Zealand.

1.4 Description of project "Clinical Overview"

Project "Clinical Overview" was organized as a regional research and development project within Region Zealand. Four parties participated in the project: Region Zealand, Imatis (the system vendor), Roskilde University and the EDs of Region Zealand. As mentioned previously, the aim of the project was to develop and implement a common EW system for all four EDs (ED1, ED2, ED3 and ED4) in Region Zealand as well as evaluating the effects of implementing this system at the EDs. The overall project was divided into two phases: Development and large-scale evaluation. During the development phase the EW system was iteratively developed, evaluated and pilot implemented before being taken into use at ED1 and ED2. The large-scale evaluation phase was focused on evaluating the effects of implementing an EW system and was carried out at ED3 and ED4.

A project group consisting of a project leader from Region Zealand, a representative from the IT vendor and clinicians from ED1, ED2 and a paediatric department were primarily responsible for the development, testing and pilot implementation of the EW at ED1 and ED2. Two PhD fellows from Roskilde University (myself included) participated in the project group in the beginning of the project to gain an understanding for the project and its context. Following a participatory design inspired approach, this project group collected input from ED1 and ED2 and in cooperation with the IT vendor representative they provided this input to the developers at Imatis. When the system was deemed ready for use it was pilot implemented at ED1 and ED2 and further developed as the project group received feedback and new input for improved or added functionality.

Once the project group regarded the EW as being ready for widespread use it was implemented at ED3 and ED4 and evaluation of the effects of implementing the system were carried out. At this time major development efforts were halted and the system was provided as a complete but configurable product. Implementation of the EW followed a participatory designed oriented approach where the primary responsibility of conducting the implementation was delegated to clinicians at the two EDs. Prior to and after the implementation of the EW system researchers from Roskilde University conducted evaluations of the effects of implementing the system.

1.5 Overall research questions

My role in project "Clinical Overview" has been to research different aspects of the EW system. This work has been conducted at all four of the EDs involved in the project. Throughout my research I have taken a broad interest in investigating the effects of introducing and using electronic whiteboards in EDs. This same broad interest is also evident in the literature review reported in Paper I. The results of this review showed that EW systems affect multiple aspects of ED work e.g. working practices, communication and coordination, whiteboard role and usage, whiteboard content, clinicians' perception of the EW, patient care as well as financial and administrative aspects. Also, the review showed that there are at least four mediating factors that have an impact upon the effects of implementing EW systems. These factors contribute to how end users perceive EW systems and they are therefore important for whether or not these systems are adopted and used as intended. The mediating factors include presentation format, integration to other systems, interface design as well as development and implementation processes.

Using the literature review and the findings from this as background the overall research question for my PhD research has been the following:

What consequences for the Emergency Department clinicians' perception and usage of the Electronic Whiteboard do the interface design and implementation approach have?

With this as a point of departure I have divided my research and empirical work between two distinct but interrelated tracks of research: Design and usability evaluations of the EW interface (**Track One**) and evaluation of EW implementation processes (**Track Two**).

Table 1. List of papers and related research questions

Paper:	Reference:	Question:
Paper I	Rasmussen, R., 2012. Electronic whiteboards in emergency medicine: A systematic review. In: Proceedings of the 2nd International Health Informatics Symposium, ACM, New York, NY, USA, pp. 483-492.	General
Paper II	Rasmussen, R. and Hertzum, M., 2012. Consider the details: A study of reading distance and revision time of electronic over dry-erase whiteboard. In: Proceedings of the 12th Danish HCI Research Symposium, Sønderborg, Denmark, pp. 24-27.	Question 1
Paper III	Rasmussen, R. and Kushniruk, A., 2012. Digital video analysis of health professionals' interactions with an electronic whiteboard: A longitudinal, naturalistic study of changes to user interactions. Submitted for publication to Journal of Biomedical Informatics.	Question 1
Paper IV	Rasmussen, R., and Kushniruk, A., 2012. The long and twisting path: An efficiency evaluation of an electronic whiteboard system. Accepted for publication in proceedings of the 2013 ITCH conference	Question 1
Paper V	Rasmussen, R., and Hertzum, M., 2012. Visualizing the application of filters: A comparison of blocking, blurring, and colour-coding whiteboard information. Submitted for publication to the International Journal of Human-Computer Studies	Question 1
Paper VI	Rasmussen, R., Fleron, B., Hertzum, M. and Simonsen, J., 2010. Balancing tradition and transcendence in the implementation of emergency department electronic whiteboards. In: Selected Papers of the Information Systems Research Seminar in Scandinavia, Tapir Academic Publishers, Trondheim, Norway, pp. 73-87.	Question 2
Paper VII	Fleron, B., Rasmussen, R., Simonsen, J. and Hertzum, M., 2012. User participation in implementation. In: Proceedings of the Participatory Design Conference, ACM, New York, NY, USA, pp. 61-64.	Question 2

Under each of these tracks my research has been focused on more specific research questions. Track One has been focused on the following question:

- **Sub Question 1:** How has the user interface design affected usage of the Electronic Whiteboard and the clinicians' work practices?

Track Two has been focused on the following question:

- **Sub Question 2:** How has the implementation process affected the usage of the Electronic Whiteboard and the clinicians' work practices?

My work on these research questions has resulted in the papers adjoined to this cover paper. Table 1 lists these papers with full references and the associated research questions.

In answering the listed question and my overall research question I hope to contribute to expanding field of sociotechnical research on healthcare information systems including the design, implementation and evaluation of such systems. In the following I will present an account of existing literature on these research areas, which will be used later in this summary to position and discuss my own research within these areas.

2 Related works

The term medical informatics spans a wide range of different systems from gene mapping systems to medico-technical devices e.g. infusion pumps and patient monitoring systems. A specific category of medical informatics is *clinical informatics*. This category includes systems that clinicians use in their everyday work to store and retrieve patient information, coordinate workflows and communicate internally with each other (Wyatt & Liu, 2002). Examples of such systems are electronic health records (EHR), electronic medical records (EMR), electronic patient records (EPR), computerized physician order entry (CPOE) and electronic picture archive and communication systems (PACS). The electronic whiteboard system, which I have worked with during my research, falls into this category. As a consequence of this I have chosen to limit the scope of this related works section to focus on studies where these types of systems are researched.

As mentioned at the end of Section 1.5, I hope to contribute to the field of sociotechnical research within healthcare information systems. In the following, I will briefly outline the basic principles of the sociotechnical approach regarding the implementation of technology in general and healthcare information systems in particular. Following this I will look separately at the technological and organizational aspects and relate the reviewed literature to each of these. Since the technological and organizational aspects cannot truly be separated I conclude the chapter with a review of literature that encompasses both aspects.

2.1 Sociotechnical systems development in healthcare: A two legged approach

Leonard-Barton (1988) presents a sociotechnical framework for the implementation of new technologies in organizations. In the paper, Leonard-Barton (1988) states that there will always be misalignments between organizations and new technologies no matter how thoroughly the user environment has been studied. Leonard-Barton (1988) argues that these misalignments present opportunities for improving both the technology and the organization through a process of mutual adaptation. Leonard-Barton (1988) states that the implementation of a new technology has to be managed actively to achieve an approximate fit between the technology and the organization. This fit is achieved via an adaptation of technology, organization or preferably both. Leonard-Barton (1988) argues that this adaptation occurs in cycles that can lead to either minor or major changes in both technology and organization, which in turn influences the implementation of the new technology.

Berg (1999) introduces the sociotechnical approach to the domain of healthcare information systems. Using many of the same arguments as Leonard-Barton (1988), Berg (1999) argues that the technological and organizational aspects of implementing healthcare information systems cannot be separate from each other but should be considered as a combined whole. Berg (1999) also states that the implementation of a new technology should be considered and managed as an organizational change process.

Table 2. 2x2 matrix shows how the reviewed design papers relate to concepts of user involvement and iterative design.

	Users as informants	Users as participants
Iterative	Bang & Timpka, 2007; Bardram, 2000; Beuscart-Zéphir et al., 2010; Patel & Kushniruk, 1998; Rinkus et al., 2005	Bardram et al., 2006; Hasvold & Scholl, 2011
Non-iterative	Jaspers et al., 2004; Nemeth et al., 2005; Salman et al., 2012; Viitanen 2009	Hyun et al., 2009; Thursky & Mahemoff, 2007; van der Mejiden et al., 2001

Berg (1999) points to placing the users centre stage during the implementation of healthcare information systems to ensure support, commitment and user-driven design and implementation. Furthermore, Berg (1999) argues that the user environment has to be experienced by designers in order to truly obtain a deep understanding of the context in which the new system will be used. Finally, Berg (1999) argues that the iterative nature of the sociotechnical approach blurs the boundaries between design, implementation and evaluation as well as the normal distinctions between designers and users.

2.1.1 The technological leg

The papers presented here chiefly concern the initial design and evaluation of different types of clinical information systems. In the review I will focus on the techniques involved in designing and evaluating these.

2.1.1.1 Design

In this section I present a review of existing literature describing the design processes employed in the development of different healthcare information systems. The main focus is on the methods applied during the design processes described in the reviewed studies. More precisely the review focuses on how users were involved in the design processes (informants vs. participants[1]) and how the design processes progressed (iterative vs. non iterative). The 2x2 matrix shown in Table 2 displays how the reviewed papers related to these dimensions.

The results of the review will be used in the subsequent discussion of the design processes involved in the studies I have performed during my PhD.

Users involved as informants

As mentioned previously, Berg (1999) states that users should be placed centre-stage during the iterative process of developing and introducing healthcare information systems. However, it is not clear from this whether the users should participate actively in the design process or if they should act merely as informants for the designers. From Table 2 it appears that the most popular approach to user-centred design in the reviewed literature is having the users involved as informants during the development process. This often entails that the users partake in the development process in an advisory role. In this role the users provide the designers with the domain knowledge necessary to design

[1] This distinction is well known from previous work on user involvement in designing information systems – see for example Cavaye (1995) and Kujala (2003).

information systems that fit well into an organization's working practices. However, they do not have a strong influence regarding how this domain knowledge is used in the design process (Cavaye, 1995; Damodaran, 1996; Kujala 2003). Domain knowledge can be acquired using a range of different methods. The reviewed literature provides examples where ethnographic inspired methods constituted substantial parts of the design processes. These methods include observational studies, interviews, document reviews, distributed cognition analysis and scenario-based design (Bang & Timpka, 2007; Bardram, 2000; Nemeth et al., 2005; Viitanen, 2009). Also included in the reviewed literature are examples of methods inspired by the principles of cognitive science used in the design process (Jaspers et al., 2004; Patel & Kushniruk, 1998; Salman et al., 2012). Patel and Kushniruk (1998) mention using the *think-aloud* method (Ericsson & Simon, 1980; Lewis, 1982) as a way of eliciting user requirements. Jaspers et al. (2004) describe a design process where the *think-aloud* method was used in this somewhat untraditional manner. Here, clinicians were asked to think-aloud while working with traditional paper-based patient records and from the verbal protocols recorded the authors were able to generate requirements for the design of a EHR system.

Iterative design is often heralded as an important part of user-centred design because it allows the designers to evaluate initial design proposals and incorporate user feedback into the system being developed (Gould & Lewis, 1985; Gulliksen & Göransson, 2001; Gulliksen et al., 2003). As indicated by Table 2, the reviewed literature regarding design processes where users have been involved as informants is divided evenly between studies that explicitly report on iterative design processes and studies, which either have not been carried out iteratively or do not mention this iterative process. Rinkus et al. (2005) provides an example of how iterative design processes are often structured.

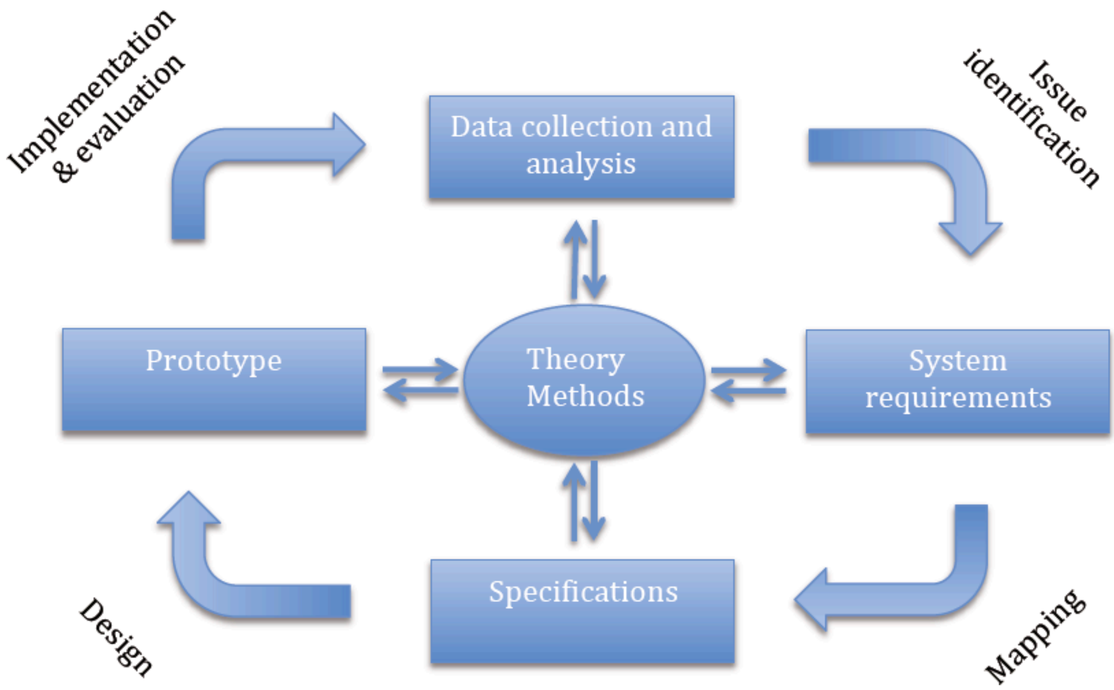

Figure 3. The Project Design Lifecycle. Reproduced from (Rinkus et al., 2005).

In this study, the authors detail how the Project Design Lifecycle was applied during the development of a distributed knowledge management system. According to Rinkus et al. (2005) the Project Design Lifecycle consists of the four phases shown in Figure 3: Data collection and analysis, System requirements, Specifications, Prototype. In the data collection phase the designers of the knowledge management system analysed the intended users working practices and their working environment. The results of this were used to identify system requirements in the second phase of the Project Design Lifecycle. In the third phase these requirements were then mapped to system specifications necessary for the design of the initial mock-ups and subsequent prototype. In the fourth phase the mock-ups were used to develop a working prototype of the knowledge management system. Potential users evaluated this prototype for usability issues and the results of this evaluation fed into another iteration of the four phases. The four phases were iterated several times before the final version was decided upon. A subsequent evaluation showed a substantial improvement over the paper-based system.

Active user participation

Another approach to placing the users centre-stage during the design of healthcare information systems is by involving them as active participants and project members. This is commonly known as participatory design (Kujala, 2003; Schuler & Namioka, 1993). Generally, in a participatory design process the involved users partake in all aspects of the design process. This includes initial analysis of user requirements, system specification, design activities and evaluations (Cavaye, 1995; Kujala, 2003). Because of this active involvement the users have a high degree of influence on the design of the final product. In a participatory design process the users can assume a number of different roles including domain experts, change agents and system champions (Rasmussen et al., 2011). As indicated by Table 2, it appears that this type of user involvement has been researched less in the reviewed literature. The papers in the reviewed literature, where active user participation was employed, describe design processes that are somewhat similar to each other in their approach to involving users. In each case the users participated as members of the design team and had influence on the final design of the systems. Hyun et al. (2009) describe a design process where two nurses were invited to participate in the design of the user interface for a nursing documentation system. The nurses and two nursing informaticians participated in two sessions in the process. The first session was aimed at eliciting requirements for the user interface. This included brainstorming nursing documentation tasks and desirable features and functions for a nursing documentation system. The second session was aimed at designing the user interface itself. Here, the nurses were chiefly responsible for the design while the nursing informaticians acted as usability consultants for the nurses in terms of confirming data format types and system functionality. The reasons for involving users as participants vary between the different studies and include a desire to create an environment to foster mutual learning and “shared construction” (Husvold & Scholl, 2011), eliciting domain knowledge from the users (Bardram et al., 2006; Hyun et al., 2009; Thursky & Mahemoff, 2007) and recruit change agents (van der Mejiden et al., 2001).

The reviewed literature also contains examples of iterative participatory design processes. In their study of the design of a surgical department operating room scheduling tool Hasvold and Scholl (2011) describe how such a design process progressed. Initially, the project group including participating users defined the service component of the system i.e. describing the purpose of the system. Using this service definition the project group designed the first version of the scheduling system via an iterative process that lasted three months. At this point the system was made available for widespread use in the surgical department. After having been in operation for two weeks key personnel were interviewed about their experience with the system and ideas for future development. This uncovered problematic issues with the system, which were further clarified using field observations of users interacting with the system. Using the results of this evaluation the designers redesigned the system in a second iterative design process focused on solving the problematic issues. After having performed changes to both the technical and organizational aspects, the second version of the scheduling tool was implemented and after a few iterations of adjustments the tool was accepted for regular use. Compared to the iterative design process described by Rinkus et al. (2005) the above describe process seems to include both minor and larger iterations instead of mainly adhering to a set number of phases. Also, the above-described process included not only redesigns of the information system but also redesigns to the work practices surround it. This was in any case not explicitly described in the Project Design Lifecycle model presented by Rinkus et al. (2005)

2.1.1.2 Usability evaluation

In this section I present a review of literature describing usability evaluations of healthcare information systems. As Berg (1999) mentions on several occasions, evaluation constitutes an important part the sociotechnical approach to developing and implementing healthcare information systems. For the technical leg of the sociotechnical approach this includes conducting usability evaluations with these systems. Usability evaluations methods are often divided between user-based empirical testing methods in one end of a spectrum and expert-driven inspection methods in the other end (Borycki & Kushniruk, 2005; Jaspers, 2009). Between these two extremes there are methods that encompass aspects of both user-based testing and expert-driven inspections. This distinction between usability testing methods and usability inspection methods is relevant in the later discussion of my own research in order to give the reader an idea of what type of evaluations I have performed.

Also, usability evaluations can be divided according to the setting in which they are performed. This varies from evaluations that are performed under conditions similar to those found in laboratories to evaluations that are performed as field-based studies. Once again, the distinction is relevant in order to position my own research within the existing literature and to provide the reader with an idea of how my evaluations have been performed.

Table 3. 2x2 matrix shows how the reviewed papers are distributed according to evaluation methods and setting. Papers that appear in multiple cells indicate either that different types of methods have been used or that a method cannot be categorized as one or the other type of method. Papers marked with an asterisk indicate a longitudinal study

	Usability testing	**Usability inspection**
Lab-based	Anders et al., 2012; Bakhshi-Raiez et al., 2012*; Fairbanks et al., 2008; Khajouei et al., 2010; Kjeldskov et al., 2010*; Kushniruk et al., 2005; Li et al., 2012; Linder et al., 2006; Peute & Jaspers, 2006; Rodriguez et al., 2002; Saleem et al., 2007; Viitanen et al., 2011b	Fairbanks et al., 2008; Li et al., 2012; Niés & Pelayo, 2010; Peute & Jaspers, 2007; Saitwal et al., 2010; Viitanen et al., 2011b
Field-based	Niés & Pelayo, 2010; Viitanen et al., 2011a; Viitanen & Nieminen, 2011; Zheng et al., 2008*	Viitanen & Nieminen, 2011; Zheng et al., 2008*

Table 3 shows how the reviewed literature on usability evaluations of healthcare information systems relate to the two dimensions described above. In reviewing the selected studies I will focus on either the results of the evaluations, the methods applied or both according to whichever aspect is relevant for the discussion of my own studies.

Usability testing in the laboratory

Usability testing methods are defined by the active participation of users during the evaluation of an information system. The common approach to such evaluations is having potential users perform predefined work tasks with the system in question while usability professionals record different metrics. This includes performance measurements, mental workload assessments, usability questionnaires and the users' verbalizations of their thoughts (Ericsson & Simon, 1980; Lewis, 1982). These types of evaluations are often conducted under laboratory conditions since multiple variables need to be controlled throughout the testing sessions in order to avoid biased results. Such laboratory conditions can be achieved by performing the evaluations in dedicated usability laboratories but often evaluations are performed in out-of-the-way places adjoined to the users normal working places. Another aspect of lab-based usability evaluation is that the tests are controlled by the usability professional in charge of conducting the evaluation and thus the focus of the evaluation is partially defined in advance.

As indicated by the distribution of papers shown in Table 3, a large amount of research has been focused on lab-based usability testing. The reviewed studies range from controlled experiments to think-aloud tests and contextual inquires. Think-aloud testing seems to be especially popular in the reviewed literature with five studies reporting having used this method as the primary evaluation method (Bakhshi-Raiez et al., 2012; Khajouei et al., 2010; Kjeldskov et al., 2010; Kushniruk et al., 2005; Linder et al., 2006). The results of the think-aloud tests were in many cases supplemented with other measurements e.g. *Time-on-Task* measurements (Bakhshi-Raiez et al., 2012), number of user interactions (Khajouei et al., 2010), mental workload measurements (Kjeldskov et al., 2010), task completion rates and questionnaire responses (Bakhshi-Raiez et al., 2012;

Linder et al., 2006). The study presented by Kjeldskov et al. (2010) is a good example of a lab-based think-aloud test. In this study, participants were asked to verbalize their thoughts while performing pre-defined tasks with an EHR system. The tests took place in a university usability laboratory, which allowed the authors to conduct multiple observations and recordings while the participants performed the tests.

Three of the reviewed studies report on controlled experiments (Anders et al., 2012; Rodriguez et al., 2002; Saleem et al., 2007). These experiments were similar to the above-mentioned think-aloud tests in the sense that the participants were asked to perform specific tasks while using the system(s) under evaluation. However, contrary to the think-aloud tests the participants were not asked to verbalize their thoughts while using the system(s). Instead, the evaluators recorded other metrics including *Delphi scores* (Anders et al., 2012), task completions times (Rodriguez et al., 2002; Saleem et al., 2007), learnability (Saleem et al., 2007), usability questionnaires (Anders et al., 2012; Rodriguez et al., 2002; Saleem et al., 2007) and mental workload measures (Anders et al., 2012; Saleem et al., 2007). Also, the controlled experiments all evaluated two systems against each other in an attempt to answer specific hypothesis regarding different aspects of the systems. Anders et al. (2012) describe a controlled experiment where two interfaces (graphical vs. tabular) for the same system were compared in terms of Delphi-scores, mental workload (NASA TLX scores) and perceived system usability. The results of the experiments showed that the users performed significantly better, experienced lower mental workload and rated usability higher with the graphical display.

The remaining four studies located in the lab-based usability testing cell in Table 3 report on evaluations where usability testing methods were combined with usability inspection methods (Li et al., 2012; Peute & Jaspers, 2007; Viitanen et al., 2011b) or evaluations where the applied method combined aspects of both usability testing and inspection methods (Fairbanks et al., 2008). These four studies will be addressed in the following sections.

Usability inspections in the laboratory

Usability inspection methods are characterized by being performed solely by usability professionals. Contrary to the usability testing methods described above there are no users involved in evaluations performed using these inspection methods. Usability inspection methods include heuristic evaluations, guideline reviews, consistency inspections, GOMS analysis and walkthroughs (Jaspers, 2009; Shneiderman & Plaisant, 2005; Card et al., 1980). Using these methods, usability professionals inspect the systems under evaluation to find issues that could affect the users' interactions with the system. Due to their nature and separation from the users usability inspections are often performed under laboratory conditions similar to those described above.

As indicated by Table 3 and described in the previous section, several of the reviewed studies that employ usability inspection methods combine these with lab- or field-based usability testing methods (Li et al., 2012; Niés & Pelayo, 2010; Peute & Jaspers, 2007; Viitanen et al., 2011b). This could be due to one of the drawbacks of applying usability inspection methods, namely that usability professionals may not have a proper understanding of the work domain or the users (Shneiderman & Plaisant 2005). The usability inspection methods applied in these studies include heuristic or guideline evaluations (Niés & Pelayo, 2010; Viitanen et al., 2011b), cognitive walkthroughs (Peute & Jaspers, 2007) and simulations (Li et al., 2012). Viitanen et al. (2011b) present a usability evaluation where heuristic evaluation was combined with a series of contextual inquires that partially resembled the think-aloud method. The results of the evaluation showed that the systems forced the users to take a large number of unnecessary steps to complete certain tasks. Also, the systems did not allow information transfer or integration between multiple systems, which forced the users to enter the same information in many different systems.

The simulations described by Fairbanks et al. (2008) and Li et al. (2012) are examples of evaluation methods that cannot be categorized as either usability testing or inspection methods. They resemble usability testing methods because users are involved in performing the simulations. However, they also resemble usability inspection methods because usability professionals are chiefly responsible for detecting potential usability issues i.e. the usability professionals observe the users interacting with the system and record incidents that they consider usability issues. Li et al. (2012) dub their simulation method "*Near-live" Clinical Simulation.* Using this method participating clinicians were asked to complete five predefined scenarios presented as recordings of *standardized patients* [2] with different symptoms. While completing the scenarios, user interactions with the system were observed by usability experts who noted all incidents found to present usability problems in the system.

Finally, one study reports on an evaluation where a usability inspection method was applied as the only method. Saitwal et al. (2010) describe how they employed the GOMS-KLM method in the evaluation of an EHR system. In analysing 14 tasks that the users frequently performed with the EHR system the authors find that users have to perform an average of 106 steps to complete one task with the system and that they spend 22 minutes on data entry while completing all 14 of the analysed tasks. The authors conclude their study by suggesting that there are many opportunities for improving the EHR user interface via redesigns and improvements.

Field-based testing and inspections

Field-based evaluations are distinguished from lab-based evaluations by the settings under which they are performed. Where lab-based evaluations are performed under controlled settings field-based evaluations are performed in the field and are subject to uncontrolled effects. Also, the area of focus is much less predefined than in lab-based evaluations without being completely absent. Field-based evaluations of information systems often include evaluating how the users apply these systems in their daily work practices without predefining what tasks are to be completed. This can be done both as usability testing and as usability inspection or methods that combine aspects of both these techniques.

As Table 3 shows, the reviewed literature contains studies where both usability testing and inspection methods were applied in field-based evaluations. The

[2] A standardized patient is often played by an actor trained in displaying the symptoms desired in a given evaluation (Linder et al., 2006). Standardized patients can also be presented as video recordings of actors describing symptoms (Li et al., 2012).

methods applied include user-based testing during actual work (Niés & Pelayo 2010), nation-wide questionnaire survey (Viitanen et al., 2011a), interaction sequence analysis (Viitanen & Nieminen, 2011) and analysis of logged user interactions (Zheng et al., 2008). Viitanen et al. (2011a) describe a nation wide questionnaire study of how physicians perceive the usability of their combined healthcare technology environment. The results of the study show that physicians are critical towards the systems they use daily and that there are several usability problems and deficiencies that hinder the efficient use of clinical information systems.

However, as with the lab-based evaluations there is an overlap between the field-based usability testing and inspection cells because some of the methods applied are located somewhere between these two extremes. The overlapping studies report on evaluations where two distinct but comparable methods are applied. In the evaluation of a digital dictation system Viitanen and Nieminen (2011) describe a technique called the *Interaction Sequence Illustration Method*. In the described procedure, a chief physician completed a realistic case with real patient data. During this, one of the authors observed the process and captured screenshots after each step in the process. The resulting set of screenshots were then analysed by the researchers and used to uncover what parts of the process required the most steps and why these steps were required. The results of the analysis showed that approval of a dictation required a high number of steps and that this was caused by inefficiencies in the system e.g. lack of link from dictation entry to patient journal. The method applied by Zheng et al. (2008) in the evaluation of an EHR system is somewhat similar. However, instead of analysing screenshots they analysed usage data recorded in the system's transaction database using *Sequential Pattern Analysis* and *First-order Markov Chain Analysis*. The results of these analyses showed that users did not navigate the system interface as expected. The authors conjecture that this is caused by the users tendency to prefer using features that allow entry of unstructured and narrative data to features that only accept structured text entry.

Longitudinal evaluations

Finally, the studies can be divide according to the time scale of the evaluations i.e. whether or not the evaluations were performed at more than one point in time. This includes both studies that were performed as longitudinal studies (Zheng et al., 2008) and studies where evaluations were performed at multiple points in time after the users initially started using the systems (Bakhshi-Raiez et al., 2012; Kjeldskov et al., 2010). The evaluation described in Bakhshi-Raiez et al. (2012) included two evaluation sessions that were conducted three months apart. The results of the evaluation showed that the participants' general satisfaction and perception of system usability decreased significantly over the three months. Furthermore, the results showed that the participants' effectiveness and efficiency increased and that the participants' preferences regarding search method changed over time. Finally, the results showed that the number of detected usability problems decreased over time with 33 problems found in the first evaluation and 27 in the second. This indicates that participants learned to circumvent some of the initial usability problems. These results also showed that 14 % of the found usability issues were related to the interface terminology while the remaining 86 % were related to the user interface design.

Kjeldskov et al. (2010) report similar results in a study of how user effectiveness, efficiency, mental workload and experienced usability problems changes as users transition from novices to experts. The results showed that the participants became more effective but not more efficient with the system as their experience increased. The results also showed that while some usability problems had disappeared there was still an overlap between the problems found by novices and experts. Also, new problems occurred as a result of the expert users utilizing more system features than novices. The novices experienced usability problems as more severe than the experts. Finally, the results of the mental workload measurements showed that novice users experienced a higher mental workload than experts.

2.1.2 The sociological leg

As mentioned in the introduction to this chapter, sociotechnical development and implementation of healthcare information systems is a two-sided affair where concerns for both the technological and organizational aspects have to be considered. Following the review of technologically-oriented studies presented in the previous sections I will present a review of studies that chiefly concern the implementation of healthcare information systems and evaluations of the effects of implementing such systems.

2.1.2.1 Implementation

In this section I present a review of existing literature that focuses on the implementation of different healthcare information systems. In the review I will primarily focus on the process and final outcomes of the implementations since these aspects are relevant for the discussion of my studies regarding implementation of the EW system. In the review I will relate the selected papers to the three myths presented by Berg (2001) regarding implementation of healthcare information system.

The first myth states that the implementation of a healthcare information system is a matter of "*technical realization of a planned system in an organization*" (Berg, 2001, pp. 147). Berg (2001) argues that this is incorrect seen from a sociotechnical perspective. In this perspective the organizational and technical aspects of an organization are inseparable and can therefore not be addressed individually during implementation. Thus, implementation of an information system will inevitably affect the organization and its working practices and in turn the organization will affect the design of the system being implemented. Beuscart-Zéphir et al. (2010) and Hasvold and Scholl (2011) present studies of implementations where both the technological and organizational aspects were considered. In their study of the implementation of an operating room scheduling tool Hasvold and Scholl (2011) provide a descriptive example of how implementation of an information system affects both the organization and the system. Hasvold and Scholl (2011) describe how the system was initially designed and implemented in a participatory design process. However, when the first version of the system was evaluated the users stated that they did not appreciate the structured data entry enforced by the system or the way that data entry errors were handled. Through observations of users interacting with the system during actual work the designers of the system learned the reasons for the users dissatisfaction. In a subsequent redesign process the data entry was reconfigured to allow text strings in almost all input fields and system data validation was removed. Instead the responsibility of data validation was relocated to the users of the system, which meant a significant change to both the system and the organizational work practices. Other changes to the working practices were introduced to help user learn how to work around erroneous data caused by the lack of systematic data validation. Informal evaluation showed that the second version of the scheduling tool allowed for a more flexible work process that matched the clinicians working practices better than the first version. In contrast to this, Aarts et al. (2004) and Peute et al. (2010) present examples of implementations where such considerations were not taken. In both cases the result was that the implementation projects were aborted. Aarts et al. (2004) state that the impact of implementing a CPOE system on the clinicians working practices was expected to be very low. When it turned out that the implementation did in fact have an extensive and dramatic impact on the clinicians working practices and efficiency, the clinicians and even former champions of the system turned against it. Aarts et al. (2004) conclude that the implementation failed because the implementers did not actively seek to produce a fit between the CPOE system and the organization but instead treated the implementation as a technical rollout project. Peute et al. (2010) find that a dominating focus on the technical aspects of implementing a laboratory ordering system and lack of consideration for the human, social and organizational aspects led to the subsequent implementation failure.

The second myth presented by Berg (2001) states that *"you can leave IS implementation to the IT department"* (Berg, 2001, pp. 148). As stated earlier in Section 2.1, one of the central principles of the sociotechnical approach is that users should be placed central stage during the introduction of an information system. This does not only apply to the technical design of such a system as discussed in Section 2.1.1 but also to the organizational implementation of the system. Therefore, Berg (2001) argues that the second myth is incorrect from a sociotechnical perspective and that implementation should also include future users and representatives from the organizations top-level management. User involvement is, according to Berg (2001), paramount in fostering a feeling of ownership among users and to ensure that the implemented system actually matches the users work practices. Representatives from top-level management are, however, an equal important piece of the puzzle during implementation. According to Berg (2001), user involvement often entails a multitude of input pushing the development process in many different directions. It is therefore necessary to have top-level management involved to balance this out and ensure that the project adheres to the overall vision for the organization. In a study of the failed implementation of an electronic medication-planning tool Bossen (2007) describes a project where users were involved in all aspects from design to implementation. Users participated in design workshops and were closely involved in implementing the system for pilot testing. Also, the project had support from top-level management. In general the implementation of the system met little resistance. Despite this and other beneficial circumstances, the pilot-implementation failed because the work of implementing the system was delegated to already busy clinicians and IT-departments. In a study of the barriers towards adoption and implementation of a PACS, Paré and Trudel

(2007) describe the implementation process of such a system at two hospitals. They find, among other things, that at one hospital users were involved in a sociotechnical approach to implementing the PACS. Also, top-level management participated in the project and demonstrated their supported via a leaflet published and distributed monthly to the clinicians. Three months after implementation an in-house evaluation showed that 100 % of all users preferred using the new system compared to the old system and that there was a significant improvement in productivity. Paré and Trudel (2007) conclude that the sociotechnical approach to implementing the PACS, including user- and top-level management involvement, helped ensure the successful implementation. At the other hospital the implementation of the PACS was left entirely to a group consisting of one technologist and two technicians. Users were not involved in the process and all considerations for organizational or human issues were put aside. When users voiced their dissatisfaction with the system the administration made it mandatory for the users to use the system. The end result of this very technological oriented implementation approach was that the system had not been fully integrated with local working practices 15 months after implementation and that no gains in productivity had been achieved. In conclusion the authors state that part of a successful implementation requires the active and sustained involvement of key actors with the right skills and interests (Paré & Trudel, 2007).

The third myth addressed by Berg (2001) is that *"IS implementation can be planned, including the required organizational redesign"* (Berg, 2001, pp. 149). Here, Berg (2001) states that it is important to have a set of ultimate goals for an implementation process. However, these aims should not be allowed to form an attempt to fully control the implementation process. Berg (2001) argues that the process of implementing information systems in healthcare organizations is *"fundamentally unfit for a planning and controlling approach"* (Berg, 2001, pp. 150) due to the combined complexity of the IS system, the organization and the work performed as well as the sheer number of stakeholders affected by the implementation. Therefore, unplanned and emergent changes should not be seen as obstacles to overcome but instead as opportunities for creating new and beneficial ways of using the system or redesigning the organization (Berg, 2001). Orlikowski and Hofman (1997) describe these emergent changes as part of their improvisational model for organizational change. They state that during the implementation of information systems in an organization three types of changes are likely to occur: Anticipated changes, opportunity-based changes and emergent changes. Anticipated changes are those changes that are planned beforehand while the two last change types are unplanned. Opportunity-based changes occur as the result of the system affording the users new ways of structuring their work and are introduced intentionally with a specific purpose during the implementation. Emergent changes, on the other hand, are neither anticipated nor intentionally introduced but rather develop tacitly over time under certain organizational contexts and become part of the organizations working practices. The changes to organization and system described by Hasvold and Scholl (2011) in their study of the implementation of an operating room scheduling tool can be seen as an example of an opportunity-based change. As described previously in this chapter, the first field evaluation of the system showed that the clinicians were dissatisfied with the initial approach to data input and data entry validation. This led to intentional changes to both the system and the working practices surrounding it. Subsequent evaluations indicated that these changes had a positive effect on the clinicians' satisfaction with the system.

2.1.2.2 Evaluation of implementation effects

In this section I present a review of existing literature focused on evaluating the effects of implementing healthcare information systems. This includes studies of how introducing healthcare information systems has affected the working practices of healthcare organizations as well as studies of how healthcare information systems have been adopted by clinicians. McGowan et al. (2008) and Cusack and Poon (2013) present a toolkit for the evaluation of such implementation effects. In this toolkit a number of metric categories are proposed as ways of measuring the effects of implementing healthcare information systems. These categories include:

- Clinical outcome measures
- Clinical process measures
- Provider adoption and attitude measures
- Patient knowledge and attitude measures
- Workflow impact measures
- Financial impact measures

The papers reviewed in this section fall into either the *provider adoption and attitude measures* or the *workflow impact measures* categories. The evaluation toolkit provides examples of different types of metrics for each category. For the *provider adoption and attitudes measures* category the toolkit suggests measuring system usage, state of transition from paper-based to electronic system and user satisfaction with a new system (Cusack & Poon, 2013). The reviewed studies present examples of evaluations where metrics such as clinician acceptance and attitudes (Chin & McClure, 1995; Mc Quaid et al., 2010; Pynoo et al., 2012), clinician satisfaction (Niazkhani et al., 2009), clinician productivity (Chin & McClure, 1995), patient satisfaction (Chin & McClure, 1995), perceived usability (Mc Quaid et al., 2010), mental workload (Hertzum & Simonsen, 2008) and system utilization (Chin & McClure, 1995) were measured. Two of these studies are described in further detail in the following.

Pynoo et al. (2012) describe a longitudinal study of how physicians' attitudes towards a PACS changed during implementation. The authors use the constructs of the Unified Theory of Acceptance and Use of Technology (UTAUT) model (Venkatesh et al., 2003) to measure physician attitudes towards the PACS three times during the process (at the time of implementation, four months after initial implementation and one year and four months after implementation). The results of the data analysis show that the clinicians' acceptance of the PACS was influenced by *performance expectancy*, *effort expectancy* and *social influence*. Initially acceptance was primarily affected by *effort expectancy* and *social influence*. Four months after implementation acceptance was primarily affected by *performance expectancy* and *social influence*. The same pattern was found one year and four months after implementation. The authors use the results to outline a number of managerial implications and argue that implementers of a

PACS should consider creating an environment where use of the PACS is strongly encouraged (*social influence*) as well as creating training programs that initially focus on ease-of-use (*effort expectancy*) and later shifts focus to harder tasks and more advanced features to allow the clinicians to truly gain from using the system (*performance expectancy*).

Niazkhani et al. (2009) report on a pre-/post implementation study of the outcomes of implementing the same CPOE system at two departments. The authors measured user satisfaction with the system using a questionnaire survey. The results showed that nurses at one department were generally more satisfied with the new system while nurses at the other department did not perceive the new system as being any better than the paper-based system. The authors argue that nurses at the first department were more satisfied because the working practices associated with the CPOE system closely resembled their work practices with the paper-based system. Nurses at the other department, however, had to adjust to an entirely new work practice, which the authors argue affected their satisfaction with the system.

For the *workflow impact measurements* category the implementation evaluation toolkit describes a number of different metrics that are suitable for measuring how the implementation of health information systems affects workflow in clinical settings (Cusack & Poon, 2013). This includes measuring changes to workflow effectiveness and efficiency, changes to time spent on patient care and investigating general changes to work practices. The reviewed studies present evaluations where different metrics were measured. These metrics include changes to time spent on direct patient care (Hertzum & Simonsen, 2012), changes to overall turnaround time for antibiotic medication administration (Cartmill et al., 2012) and clinicians' perceived effects on workflow efficiency (McAlearny et al., 2010). In the following one of these studies is described in more detail.

In a pre-/post implementation study adjoined to project "Clinical Overview" Hertzum and Simonsen (2012) investigate how the EW system affects working practices at an Emergency Department. Among other things, the authors measured before and after system implementation how much time clinicians spent in patient rooms and at the department control desk as well as usage of computers in patient rooms. The results of the study showed that after implementation nurses spent more time in patient rooms and less time at the control desk. Physicians on the other hand spent more time at the control desk after implementation. The authors argue that because the nurses are generally more experienced they feel comfortable working on their own and because the EW system allows distributed access they can retrieve information regarding new tasks using computers in the patient rooms. This negates the need to return to the department control desk and allows the nurses to spend more time with one patient before proceeding to the next. Physicians on the other hand are generally inexperienced and often under training while working at the department. They may therefore be inclined to seek advice from colleagues gathered around the control desk, which unfortunately takes time away from direct patient care. From the results of measuring usage of computers in patient rooms the authors find that the clinicians do not utilize all the advantages of the EW system e.g. accessing patient care related programs through the EW application while using patient room computers. The authors argue that the lack of a firm organizational implementation approach could have caused this laissez faire utilization of the EW systems advantages.

2.1.3 Design in use: Standing tall on both legs

As mentioned in the introduction to this chapter and in Section 2.1 the organizational and technological aspects of designing and implementing information systems in organizations should and in fact cannot be considered separately according to the sociotechnical approach. Following the arguments stated by Berg (1999) and Leonard-Barton (1988) these two aspects need to be considered as a whole to ensure a successful fit between the organization and the information system. Furthermore, the sociotechnical approach, as presented by Berg (1999), does not distinguish between the traditional phases of analysis, design, implementation and evaluation. Instead, these activities seem to blend into each other in an iterative design and implementation approach (Berg, 1999). Also, Berg (1999) states that with the sociotechnical approach the distinctions between designers and users start to blur as users take on a more active role in the development of information systems. A specific strand of systems development research has investigated system development efforts where this blurring of phases and roles has been taken very literally. Trigg and Bødker (1994) describe a study of how newly installed word-processing software was continuously *tailored* by skilled super users in an effort to increase their own and their colleagues efficiency with the system. However, the tailoring efforts did not only affect the system but also the working practices surrounding it. Trigg and Bødker (1994) conclude the paper by stating that future system development efforts should take tailoring into account as a way of creating information systems that truly fit into the intended organization and provide opportunities for users to perform alterations to the system to better fit with their working practices. In their study of participatory design practices, Dittrich et al. (2002) radicalize this approach and dub it *design in use*. Dittrich et al. (2002) state that the *design in use* approach effectively removes the distinctions between designers and users and places the responsibility of designing and implementing information systems with what they call *shop floor IT managers.* Following the same ideas presented by Trigg and Bødker (1994), Dittrich et al. (2002) conclude that future software development efforts should focus on developing information systems that are easy to reconfigure and tailor locally by the intended users. Also, Dittrich et al. (2002) conclude that the role of local *shop floor IT managers* should be given a more prominent position in organizations and that resources should be dedicated to the work performed by these individuals. Hartswood et al. (2003) expand the *design in use* concept into the realm of developing healthcare information systems and introduce the concept of *co-realisation*. This approach to developing IT system implies that users and IT professionals should participate in:

"…a shared, situated practice… that is grounded in the lived experiences of users as they grapple with the problems of applying IT, appropriating its functionalities and affordances into their work practices and relations. Only in this way can designers truly get to understand the users' work and their changing needs." (Hartswood et al., 2003, pp. 394)

Hartswoord et al. (2003) state that their approach aims at bringing the design of IT systems into the working places where the developed systems will be used. By doing this the users are given the opportunity to fully explore the possibilities of adopting and adapting to the new system and provide feedback as the design process progresses. In this approach the IT professional acts as an *IT facilitator* with the main goal of helping the users realise their needs as they develop the organization and the information system together. Through a pilot study where the *co-realisation* was employed, Hartswood et al. (2003) find that through interactions with the users the role of the *IT facilitator* evolved to not only include aspects of system design and development but also aspects of using the system. Furthermore, Hartswood et al. (2003) find that the *IT facilitator* needs to reflect upon how user expectations are managed throughout the project as there is a possibility of conflicts of opinions arising due to the spontaneous and opportunistic nature of the interactions with the users. Finally, the authors find that user requirements often emerged outside of formal user-designer meetings e.g. through the discovery of defects and deficiencies in the system during usage. In this context, the authors also find that new design possibilities emerge as the users become more experienced and start requesting modifications and expansions to the system to better fit with their evolving working practices. In agreement with Berg's (1999) statement that designers need to experience the users working environment, Hartswood et al. (2003) conclude that IT professionals need to become users and experience the working practices within the organization in order to be able to develop systems that support the work of the end users. In the same vein users also need to become adept designers of the technology they use in their everyday working practices (Dittrich et al., 2002).

3 Method

In my research I have utilized a range of different research strategies, data collection and analysis methods. Since the adjoined papers describe the individual data collection and analysis methods in detail for each study, I will only briefly introduce them here and instead focus on describing my overall research strategy and how the different methods fit into this. Also, I will provide a brief summary of the data collected throughout my research. Finally, I will discuss the advantages and challenges of working in an empirically driven fashion.

3.1 Research design and strategy

In designing my doctoral research I decided to perform a series of independent but related empirical studies with the aim of uncovering a range of aspects regarding the EW system and answering my overall research question. Using McGrath's (1981) classification of research strategies these studies can be categorized into two strategies: Laboratory Experiments (Papers II and V), Field Studies (Papers III-IV and VI-VII). Paper I falls outside of these strategies due to its non-empirical nature. Following McGrath's (1981) argumentation that all individual research strategies are fundamentally flawed and that researchers should employ multiple strategies when researching an object of interest, I argue that having used more than one research strategy has allowed me to gain a wider understanding of how the EW system is perceived and used by the ED clinicians. This also points to the role of this cover paper in which the different studies are collected and discussed against each other to provide a comprehensive picture of the effects of introducing EW systems.

3.2 Data collection methods and tools

Throughout my research I have utilized a range of different data collection methods and tools. Paper I reports on a review of the existing literature on EW systems in emergency medicine. This review was carried out following the guidelines for structured literature reviews described by Kitchenham et al. (2004). Papers II and V report on two controlled experiments. During each experiment different tools were used for collecting data e.g. task times, video-, audio- and screen recordings, TLX forms, questionnaires and observer notes. Papers III and IV report on the results from a naturalistic and longitudinal usability study of the clinicians' interactions with the EW system. During this study, screen-recording software and on-site observations were employed in capturing the clinicians' interactions with the EW system and any potential usability issues. Finally, Papers VI and VII report on two interconnected studies where implementation processes as well as the clinicians' usage and perception of the EW system were studied. In these studies qualitative interviews and observations of clinicians and the EW system were utilized.

3.3 Data analysis methods

In analysing the collected data I have utilized a variety of analysis methods. These methods were selected according to the aim of the study and the associated paper. In the following I have categorized the different methods in qualitative and quantitative methods and will briefly touch upon the analysis methods used.

3.3.1 Qualitative methods

Four studies (Papers I, III, VI, VII) utilized primarily qualitative analysis of collected data. In Paper I the analysis of the reviewed articles consisted of a thorough reading of the articles and summation of the contents to create an overview of the different results. The analysis in Paper III consisted of a real-time viewing of the screen recordings and concurrent logging of user interaction with the EW. The resultant log files were coded afterwards to identify usability problems and enable comparison across recordings. Papers VI and VII use similar analysis methods but instead of video recordings the primary objects of analysis were the observation notes, audio recordings and interview notes.

Qualitative data analysis was employed in paper V in the analysis of the video- and audio recordings. This analysis was carried out using a method similar to the one used in paper III.

3.3.2 Quantitative methods

Quantitative methods were used as the primary data analysis methods in three studies (Papers II, IV, V). Data analysis in Papers II and V was performed as statistical ANOVA analysis of the data collected through the controlled experiments using a number of different dependent and independent variables. The calculations were performed using statistical analysis software. In Paper IV the initial logging and coding of user interaction with the EW system was performed using the same approach as in Paper III. However, the coded log files were analysed in a quantitative manner using the GOMS-KLM method (Card et al., 1980).

3.4 Summary of data

Table 4 displays an overview of the data collected throughout my research and the different analysis methods applied. As can be seen from Table 4 and read in the previous sections these data stem from a number of empirical studies and encompasses a range of different data. In combination these data and the analysis of them make up the empirical foundation for this thesis and the adjoining papers.

3.5 Permissions and informed consent

Due to the empirical nature of my research, all studies except one have been performed at the EDs involved in the project. This meant that the ED clinicians had to be informed about the purposes of the different studies, their roles in the studies and what the results would be used for. In the studies where a fixed number of clinicians participated (e.g. controlled experiments and interviews) this was done as part of the briefing before the studies were conducted. In the controlled experiments the participants were also asked to sign a form where they declared that they had been informed about the aims of the study and what the results would be used for.

Table 4. Summary of collected empirical data

Paper	Data collection method	Types and quantities of data	Primary analysis method
Paper I	Structured literature review	21 articles	Qualitative Article reading
Paper II	Controlled experiment	72 task times 17 audio recordings 18 questionnaires	Quantitative ANOVA
Paper III - IV	Naturalistic longitudinal usability study	166 hours of screen recordings 2 pages of observer notes	Qualitative and quantitative Coding and analysis of video content GOMS-KLM calculations
Paper V	Controlled experiment	648 task times 648 TLX forms 648 task questionnaires 18 participant questionnaires 27 video-, audio- and screen recordings	Quantitative ANOVA
Paper VI	Observations Interviews	65 pages of observations notes 6-8 pages of interview notes	Qualitative Coding and analysis of observation and interview notes
Paper VII	Interviews	Approx. 17 hours of audio recordings Approx. 60 pages of interview notes	Qualitative Coding and analysis of audio recordings and notes

However, in the studies where an arbitrary number of clinicians participated e.g. field studies, providing this information to each individual clinician posed more of a challenge. In these cases information regarding the studies were provided to the clinicians through multiple channels. Firstly, the clinicians had been advised that the EDs participated in project “Clinical Overview” and therefore were aware that researchers would be conducting different activities at the departments. Secondly, I took measures to ensure that clinicians on duty during my studies had been informed during morning conferences of the day of the study. Finally, during the field studies clinicians were provided information regarding these if they enquired. As part of this, it should be mentioned that there is not the same tradition for formally requiring and obtaining informed consent regarding research activities in Denmark as there is for example in the USA, Great Britain and other countries.

One study (Papers III and IV) involved recording live patient data without the possibility of informing the patients of this. This required that the Danish Data Protection Agency (DDPA) had approved the study prior to it being conducted. Approval from the DDPA entailed that the raw data was stored securely on password-protected media and that I alone had access to viewing the data.

Since my research has been conducted in the context of a larger research project (Clinical Overview) the studies I performed had to be negotiated with the project group. This was a prerequisite to ensure that there was a clear coherence between the studies and the goals of the overall project. Negotiation included specifying and presenting the scientific aims of each study to the project group and incorporating their feedback into the aims of the studies. For the study reported in Paper V the project steering committee had to approve the experiment. This was necessary because preparations for the experiment required spending project funds on developing prototypes and compensating the emergency departments for the clinicians' participation in the experiment.

3.6 Discussion of research strategy: Covering all the bases

As stated in Section 3.1, I argue that having used two distinct research strategies (laboratory experiment and field studies) has allowed me to gain a more comprehensive understanding of the EW system and its effects upon the EDs. Each performed study has in some way shed a new and different light on how the EW system has affected the working practices of the EDs after its introduction and how the implementation processes and user interface design has affected the clinicians' perception of the system and their usage of it.

McGrath (1981) states that all research strategies should in one way or another strive to fulfil three conflicting desiderata including: a) "*precision in control and measurement of variables related to the behaviors of interest*", b) "*existential realism, for the participants, of the context within which those behaviors are observed*" and c) "*generalizability with respect to populations*". When viewing my research as a whole I have taken different steps in order to fulfil these desiderata. Precision in control and measurement has been the primary desideratum in focus for the controlled experiments (Papers II and V). Conversely, realism has been the desideratum in focus for the field studies performed (Papers III, IV, VI, VII). The third desideratum, generalizability, has not been the primary focus in any of the completed studies. However, different steps in my research have been taken to improve generalizability. Firstly, my research activities have been spread out between the four EDs involved in the project. I argue that this improves generalizability compared to having carried out research at only one ED but at the same time I acknowledge that my empirical research is still confined to Region Zealand. Secondly, I have compared and contrasted the results of my individual studies in each of the adjoined papers. Third and finally, I will in this cover paper contrast and compare my empirical findings with the related work described in Section 2. In doing this I argue that the generalizability of my research and knowledge regarding EW systems is improved and transcends the borders of Region Zealand.

Having used multiple research methods throughout the different studies has also proven to be a challenge of working in the empirically driven approach described above. The challenge in this case is that the results from the different studies are of a different nature, which makes it difficult to compare the results directly across studies. Instead comparisons will have to be made on a more general level and instead focus on integrating the results of the different studies. This will be done in Chapter 5, where the results of the performed studies are discussed against each other and the related work described in Chapter 2.

4 Results

The results of the studies performed throughout my research have been reported in seven papers. The seven papers have all been submitted as either conference contributions or as journal papers. Furthermore, Papers I, II, IV, VI and VII have been accepted and will be or have already been published in the proceedings of the conferences to which they were submitted. In the following I will describe in the form of extended abstracts the motivation for each study, the methods applied and the results of each study.

4.1 **Paper I:** Electronic whiteboards in emergency medicine: A systematic review

The motivation for the study reported in Paper I was the realisation that EW systems are becoming increasingly popular in EDs as replacements for manual dry-erase whiteboards and that this creates a need for clarifying the effects of implementing these systems. Paper I seeks to provide this clarification and partially answer the overall research question via a systematic literature review of existing studies of EW systems.

Following the guidelines described in Kitchenham et al. (2004) the literature review was carried out using a four-step search process aimed at retrieving a broad selection of studies on EW systems. Initially, three automated searches using a number of different keywords and search terms were performed with Google Scholar, ISI Web of Knowledge and PubMed. Second, six journal searches were manually performed using the databases of two healthcare informatics journals, two healthcare journals and two human-computer interaction journals. Thirdly, the references of the already selected articles were perused for relevant articles not found during the first two searches. Fourth and finally, a search using ISI Web of Knowledge was carried out to find articles that referred to the already found articles. In total 21 articles were selected for review.

Data was retrieved from the selected articles via a thorough reading and writing a summary of the contents. Besides the summary, the retrieved data included a range of relevant information e.g. the source of the articles, full references, methods, main topic and settings. These data were tabulated in order to compare the results and allow a discussion across the reviewed articles.

In conclusion, Paper I finds that EW systems influence the work at EDs in a number of different ways e.g. changes to work practice and changes to whiteboard information accuracy. Also, the review finds that there are mediating factors that have an impact upon these effects e.g. display format, user interface design and integration with other clinical IT systems. However, the results of the reviewed articles are somewhat inconclusive and of a mixed nature and therefore the final conclusion of Paper I is a call for more focused and specific research on the effects of implementing EW systems and what mediating factors influence these effects.

4.2 **Paper II:** Consider the details: A study of the reading distance and revision time of electronic over dry-erase whiteboards

The motivation behind the study reported in Paper II was an interest in clarifying how certain seemingly mundane design details of the EW system influenced its usability. In this study the EW system was experimentally compared to the previously used dry-erase whiteboard with regards to effective reading distance and revision time.

The study was designed as a within-subject study where 18 participants solved a reading task and a revision task using first the EW system and then the dry-erase whiteboard. The reading task consisted of reading out loud the contents of three whiteboard rows. The contents were read at decreasing distances to the whiteboard, first 5, then 3.5 and finally 2 meters. The revision task consisted of two subtasks: Changing the triage code for a specific patient and entering transfer-to-ward information for another patient. After having completed both tasks each participant rated the ease of use for each whiteboard and ranked the whiteboards according to preference.

Data were collected using audio recordings for the reading tasks and preference ranking. Accuracy of the reading task data was rated by comparing the audio recordings to the actual contents of the whiteboard. For the revision task a digital stopwatch was used to record task completion times for each subtask. The collected data were analysed using analyses of variance (ANOVA). The results of the ANOVA analyses showed that participants read the EW with inferior accuracy at all three levels of distance compared to the dry-erase whiteboard. For the revision task the ANOVA analyses showed that participants solved the first subtask faster with the dry-erase whiteboard and that there was no difference between the two whiteboards for the second subtask. Analysis of the ease of use and preference data showed that the participants found both whiteboards easy to use but preferred the EW due to a number of reasons.

In conclusion Paper II finds that design details that might seem mundane and trivial can affect the usability of EW systems. In this case the smaller font size of the EW system makes it harder to read the whiteboard contents at a glance, which in turn could slow down the work pace of the ED clinicians. Furthermore, Paper II concludes that the logon process associated with using the EW system does not necessarily consume more time compared to using the dry-erase whiteboards suggesting that the logon process fits well into the ED work. In the final conclusion Paper II calls for field evaluations of systems such as the EW in order to tease out design details that might otherwise go unnoticed and in the end degrade system usability.

4.3 **Paper III:** Digital video analysis of health professionals' interactions with an electronic whiteboard: A longitudinal, naturalistic study of changes to user interactions

The underlying motivation for the study reported in Paper III was an interest in uncovering what usability issues the users of the EW system encountered during everyday use of the system and how these issues change over time as the clinicians gain more experience with the system. Also, we were interested in testing how effective the used evaluation methodology was in detecting usability issues.

The study was designed as a naturalistic and longitudinal field evaluation of the clinicians' interactions with the EW system. User interactions were recorded over a five-day period at one ED approximately 1.5 years after implementation of the EW, then at a second ED were the EW had been in use for 1.5 months and finally at the same ED 5.5 months after implementation. User interactions with the EW system were recorded using screen-recording software running on the machines from which the clinicians access the EW system. The resulting recordings were analysed by viewing each video file and logging all user interactions and usability issues using a predefined scheme.

The initial results showed that the clinicians encountered both system-related and user-related usability issues. These results were subsequently tabulated to allow for comparison between the two EDs and between different levels of experience with the EW system. This showed that the system-related as well as some of the user-related issues did not change as a result of the clinicians gaining more experience with the EW system. However, the tabulated results showed that some specific work patterns did in fact change as the clinicians gained more experience with the system. These work patterns were related to the users efficiency with the EW system and in some cases their efficiency increased as they gained experience with the system. In other cases, however, their efficiency decreased as the users gained more experience with the EW system. Finally, the results of the analysis also showed that the methodology used for collecting and analysing data was capable of finding a broad range of usability issues that might not have been found using traditional usability evaluation methods.

In conclusion, Paper III calls for more focus on longitudinal and naturalistic usability evaluations and encourages other researchers to use and refine the methodology used in the study in order to hopefully improve the usability of healthcare information systems.

4.4 **Paper IV:** The long and twisting path: An efficiency evaluation of an electronic whiteboard system

Paper IV reports on a subset of the results produced in the study reported in Paper III. However, the motivation behind this study was not uncovering how usability issues and work patterns change over time but rather on how a redesign of the EW system's user interface could make the system more efficient to use.

Using the same data analysis approach as described in Section 4.3, Paper IV finds that the EW system forces the users to follow complicated and unnecessarily long sequences of steps when completing specific tasks with the system e.g. adding new patients. Calculations using the GOMS-KLM method showed that the clinicians would spend approximately 157.2 hours each year following the sequence of steps dictated by the EW system when adding new patients. Applying the same GOMS-KLM calculations to a theoretical redesign of the EW interface showed that this time could be reduced by approximately 45 % if the EW was redesigned accordingly. This redesign could have a widespread effect on the efficiency of the EW system since there are more areas where the system dictates long and complicated sequences of steps that would be affected and improved as a result. Also, since the EW system is currently being implemented at an increasing number of departments across Region Zealand the possible time savings of the proposed redesign might be even more substantial.

In conclusion, Paper IV finds sizeable inefficiencies in the design of the EW system and calls for an increased focus on conducting more and earlier usability evaluations of healthcare information systems such as the EW in order to improve the efficiency of these systems.

4.5 **Paper V:** Visualizing the application of filters: A comparison of blocking, blurring, and colour-coding whiteboard Information

The study reported in Paper V was motivated by an interest in investigating how information visualization techniques could be incorporated into the user interface design of the EW system to improve support for the ED clinicians' work practices. Three EW prototypes utilizing different ways of visualizing the application of information filters (blocking, colour-coding and blurring) were compared experimentally to uncover which supported clinicians best in solving realistic work tasks.

The study was designed as a mixed-design experiment where 18 clinicians participated in two sessions; one individually and one together with another clinician. During each session participants solved six realistic tasks with each of the three prototype interfaces. During the shared sessions the participants had to agree on how to access the EW system. Also, they did not cooperate as such since each participant worked on different tasks. After solving each task participants were asked to fill out a TLX form and a usability questionnaire regarding the interface used.

Using ANOVA the collected quantitative data (task completion times, TLX forms, usability questionnaires) were analysed using interface type (blocking, colour-coding, blurring), session type (individual, shared) and profession group (physician, nurse) as independent variables. The qualitative data (video-, audio-, screen recordings) collected throughout the study were analysed by examining the different recordings and coding them according to predefined categories. The results of the analyses showed that the clinicians performed significantly faster and with less temporal demand with the blocking interface. However, the analyses also showed that the colour-coding interface provided the clinicians with a better overview of the information displayed by the EW. Also, the results showed that the blurring interface did not perform as well as expected and as previous research had shown. Finally, the analyses indicated that the clinicians worked much less in parallel than expected.

In conclusion Paper V discusses the different benefits and drawbacks of the three prototype interfaces and how these could be combined to produce an interface design that provides the clinicians with an improved overview of the information displayed and still allows swift and efficient interaction with the system. The final conclusion of Paper V is a call for research focused on the application of information visualization techniques in work situations where users of information systems share access to a system through a common artefact without directly cooperating.

4.6 **Paper VI:** Balancing tradition and transcendence in the implementation of Emergency Department electronic whiteboards

The underlying motivation for the study reported in Paper VI was an interest in uncovering how a respect for existing work practices (tradition) was balanced against improving existing or creating new work practices (transcendence) during the implementation of the EW at two EDs.

Multiple observations were conducted as the primary data collection method for this study. This included observing individual clinicians throughout a dayshift, observing the clinicians in the ED control room as well as observing the EW system and the clinicians' interactions with this. Video recordings and handwritten notes were used to capture observations. The observations were followed up and supported by interviews with the clinicians primarily responsible for the implementation process at the two EDs. These interviews were captured using handwritten notes and audio recordings.

Results of the data analysis showed that the introduction of the EW system did not negatively disrupt the clinicians' normal working practices because the implementation process allowed the EW system and the associated working practices to gradually adjust to each other. Also, the results showed that despite the EDs following two very different implementation approaches they were both successful in introducing the EW systems in a non-disruptive manner.

In conclusion, Paper VI finds that it is possible to create a balance between respecting existing working practices and improving or creating new working practices during the implementation of the EW system. In the cases reported in Paper VI this was achieved by following an improvisational process where changes to the EW system and work practices were introduced gradually as the clinicians gained more confidence in using the EW.

4.7 **Paper VII:** User participation in implementation

The study reported in Paper VII was motivated by an interest in uncovering the effects of extensive user participation in the implementation of the EW system. This was done by analysing how ED management, participating and non-participating staff members perceived the implementation process in respect to areas that have previously been linked to positive effects of user participation e.g. system quality, emergent interactions, and psychological buy-in.

Data were collected via a comprehensive range of interviews. This included interviews with; three clinicians directly involved in the implementation process, ten clinicians not involved in the implementation process and four management staff members. The collected data were analysed by first perusing the interview notes to construct an initial set of coding categories. Following this the audio recordings were coded using a grounded theory inspired approach where each recording was coded on the basis of its contents as well as by using the constructed coding categories.

The results of the analyses finds that participating staff members perceived the implementation with more uncertainty and frustration than the other two interviewee groups. Also, the results indicated that access to colleagues with relevant implementation experience is important for successful user participatory implementation. Finally, the results of the study pointed to the local configurators important role in implementing the EW system.

The final conclusion of Paper VII is that it is important to provide the needed resources for supporting a peer-to-peer network amongst participating staff members, project group members, IT developers and local IT department and that the purpose of this network is to help the participating staff acquire the skills needed to carry out the implementation process efficiently.

5 Discussion

This discussion is divided into two sections. Section 5.1 positions my research in relation to the existing literature reviewed in Section 2. Section 5.2 features a discussion of the general findings of my research in relation to each other and the existing literature.

5.1 Positioning my research

As mentioned in Section 1.5, my research has been divided between two tracks. Track One focused on investigating how the user interface design has affected usage of the EW system and the clinicians' working practices while Track Two focused on clarifying how the implementation approaches affected usage and working practices. When seen as a collective research effort the studies have a distinct sociotechnical aspect to them and therefore I find that my work is positioned within the sociotechnical tradition regarding the design, evaluation and implementation of information systems as defined by Berg (1999) and Leonard-Barton (1988).

However, the performed studies can also be positioned individually in relation to the existing literature. Papers II, III, IV and V fall under Track One due to their focus on either experimenting with or evaluating the EW system's user interface. The four studies reported in these papers consist of two controlled experiments (Papers II and V) and two field-based usability evaluations (Papers III and IV). Thus, the papers under Track One chiefly position themselves in relation to the literature reviewed in Section 2.1.1.2. Papers II and V are closely related to the studies reported by Anders et al. (2012), Rodriguez et al. (2002) and Saleem et al. (2007) due to the methods applied. Papers III and IV are closely related to Saitwal et al. (2010), Viitanen et al. (2011b), Viitanen and Nieminen (2011) and Zheng et al. (2008) in terms of methods and results. Papers II, III and IV can also be positioned in relation to the literature reviewed in Section 2.1.2.2 due to their consideration of how the investigated usability errors affect workflow efficiency.

Papers VI and VII fall under Track Two due to their focus on describing how the EW system was implemented at the four EDs involved in the project. The ethnographically inspired studies reported in the two papers are closely related to the studies reported on by Bossen (2007) in terms of the implementation approach followed as well as Hasvold and Scholl (2011) and Paré and Trudel (2007) in terms of the implementation approaches studied and the end results of the implementations. Also, Paper VI can be related to the literature reviewed in Section 2.1.1.1, due to its description of how the EW system was initially developed and designed. In this context, Paper VI is closely related to papers reporting on design processes that are either iterative (Bang & Timpka, 2007; Rinkus et al., 2005), involve users as participants (Hyun et al., 2009; van der Mejiden et al., 2001) or include both of these aspects (Husvold & Scholl, 2011)

5.2 Discussion of research findings

Since each of the adjoined papers include discussions of their findings and relate these to existing literature I will not discuss the papers individually here.

Instead, I will discuss more general findings regarding the EW systems in relation to the related works presented in Section 2.

5.2.1 Unresolved usability problems

Despite showing that the EW system is generally easy to use and appreciated by the clinicians, the results of the usability evaluations reported in Papers II-IV indicated that there are unresolved usability issues in the system's user interface that have a potential negative impact upon the clinicians efficiency with the system. This includes forcing the clinicians to follow an excessive number of steps to complete certain tasks or reduced readability of the displayed information. In this sense, these issues are similar to several of those reported in the literature (Saitwal et al., 2010; Saleem et al., 2007; Viitanen & Nieminen, 2011; Viitanen et al., 2011b; Zheng et al., 2009) in terms of type and their effect on the users' interactions with the evaluated systems.

Furthermore, the results of the GOMS-KLM analysis of the redesign proposed in Paper IV showed that it would require only minor changes to the EW system's user interface to resolve at least the issues found here and possibly also other interface usability issues. In a similar effort, Saleem et al. (2007) show that by modestly redesigning the user interface of a decision support system, they were able to significantly increase user efficiency. Also, Saitwal et al. (2007) and Zheng et al. (2009) conjecture that the issues found in their studies could be alleviated by similar redesigns. On the basis of this it seems reasonable to argue that certain efficiency issues in the EW system could be resolved by redesigning specific parts of the user interface. However, redesigning the user interface is not the only approach to resolving efficiency issues. As indicated by the studies presented by Beuscart-Zéphir et al. (2010) and Hasvold and Scholl (2011) organizational aspects can also be adjusted to compensate for such issues. Therefore, solving the issues investigated in especially Papers II and III could potentially include altering working practices and organizational aspects surrounding the EW system e.g. relocating the widescreen displays increase readability (Paper II) or more focused training on efficient user interaction with the system (Paper III).

Thus, it would appear that the EW system has potential for improvements in terms of efficiency and that these improvements could be achieved with relative ease through either minor redesigns of the user interface or by minor adjustments to the organizational aspects surrounding the system. Therefore, it seems counterproductive that these issues have not been resolved during the design and implementation of the EW system. There are numerous possible reasons for this situation e.g. the issues have not been reported or they have not been deemed important enough to fix. However, I conjecture that these efficiency issues have simply gone unnoticed by the clinicians during their efforts to adopt and adapt the EW system and their working practices and thus they have not been reported back to the project group. Another possible reason is that these efficiency issues have in fact been noticed by the clinicians but have been perceived as something that could not be changed. After the possible initial frustration the clinicians would have learned to live with these issues and as such, they have been allowed to persist in the user interface design and continue to hamper user efficiency with the EW system. Furthermore, the existence of these unresolved issues indicate that the processes of refining the EW system have not been allowed to continue long enough to find and resolve the less immediate usability issues in the system's user interface design.

5.2.2 Individual versus collaborative work

Previously published research has shown that traditional dry-erase whiteboards constituted and continue to constitute a critical tool for coordination and communication in EDs and other departments in hospitals across Europe, USA and Canada (Bisantz et al., 2010; Bjørn & Hertzum, 2011; Lasome & Xiao, 2001; Pennathur et al., 2007; Pennathur et al., 2008; Wears & Perry, 2007; Wears et al., 2007; Xiao et al., 2007). A number of studies on EW systems have shown that this type of system, if designed appropriately, has the ability to preserve and in some cases improve upon the positive qualities of the traditional dry-erase whiteboards and thus effectively replace the dry-erase whiteboards as the central artefact for collaborative work practices among clinicians (Abujudeh et al., 2010; Aronsky et al., 2008; Bardram et al., 2006; France et al., 2005; Wong et al., 2009). For example, Bardram et al. (2006) demonstrated how an EW system, that combines computer technology and desirable features of dry-erase whiteboards, improved the coordination work at a surgical ward. By streaming live video from operating rooms and displaying information related to different aspects of awareness the EW system allowed the clinicians to reduce interruptions and react quicker to changes in the operating schedule. The results of these studies correspond with my own observations of EW system being used in a collaborative and parallel manner by clinicians working with and around the system.

However, parts of the results from the experiment presented in Paper V seem to contradict these observations and the previously published studies. With the limitations of an experiment, these results indicated that for some tasks e.g. updating and retrieving information there might be a tendency for the clinicians to generally prefer working sequentially when using the EW system. However, I would argue that the contradiction between the results of the experiment and the previously published research is not necessarily an indication of conflicting results. Like the CPOE system studied by Niés and Pelayo (2010), it is possible that EW systems need to fulfil more than one mode of operation. The tasks performed during the experiment were structured to realistically mimic tasks that the clinicians would encounter during their usage of the EW system. These tasks were characterized by requiring extended interaction with the EW system while the participants searched, retrieved and updated information regarding specific patients. On the other hand, the collaborative work tasks described in the existing literature do not require such interaction with the EW system but are instead characterized by discussions regarding information displayed and are often shorter in duration. As demonstrated by Niés and Pelayo (2010), it is important in such a situation that a user interface is designed to support all types of operation modes in order for the system in question to support all aspects of the users working practices. Clarifying whether or not this is the case for EW systems requires more focused research on this issue and should be considered in future redesigns of the user interfaces for EW systems.

5.2.3 Respect tradition while experimenting with transcendence

As witnessed by several of the papers reviewed in Chapter 2, creating systems that fit easily into existing work practices is often a governing consideration during the design and implementation of healthcare information systems. This is among other things evident from the high number of user-oriented design- and implementation processes presented by the studies reviewed in Section 2.1.1.1 and Section 2.1.2.1 respectively. However, as discussed by Ehn (1988) and Mogensen (1992) it can be difficult to significantly improve an organization's working practices if the current practices are not challenged or provoked during the design of new information systems. Ehn (1988) states that designing information systems requires finding a balance between not disturbing the core of the existing working practices (i.e. *tradition*) and still changing or improving these practices (i.e. *transcendence*). Using the constructs of the UTAUT model (Venkatesh et al., 2003), the organizational level considerations presented by Ehn (1988) and Mogensen (1992) can be transferred to the level of the individual user.

As described by Venkatesh et al. (2003), the UTAUT model combines a number of previous technology acceptance models e.g. TAM (Davis et al., 1989) and diffusion of innovations theory (Rogers, 1995), and can be used to predict the future users' intentions to accept and start using a new information technology e.g. a healthcare information system. In their outline of the UTAUT model, Venkatesh et al. (2003) find and state that there are four constructs that have an effect on the intentions of the users to accept and use a new technology. These four constructs are: *Performance expectancy, effort expectancy, social influence* and *facilitating conditions* – see Figure 4. In the following I will limit my discussion to only include the constructs of *performance expectancy* and *effort expectancy*. *Performance expectancy* is defined, as "*… the degree to which an individual believes that using the system will help him or her to attain gains in job performance.*" (Venkatesh et al., 2003, pp. 447). *Effort expectancy* is defined as the "*…degree of ease associated with the use of the system.*" (Venkatesh et al., 2003, pp. 450). According to Venkaktesh et al. (2003), *performance expectancy* and *effort expectancy* are both strong predictors of a person's intention to accept and start using a new technology. However, the two constructs differ in respect to when they have the strongest influence. While *performance expectancy* remains a strong indicator of user acceptance throughout the lifetime of a new information technology, *effort expectancy* is strongest during initial stages of usage and decreases over time to become non-significant as a result of sustained use.

Hennington and Janz (2007) adapt and expand the UTAUT model to a healthcare context and introduce issues for each construct, which they find are especially relevant for this specific context. For *performance expectancy* this includes among others things the clinicians' perceptions of how well a healthcare information system fits with the existing working practices as well as their perception of how the system will improve the quality of care. For *effort expectancy* the adaption to the healthcare context includes the clinicians' perceptions of the effort required to start using the new system.

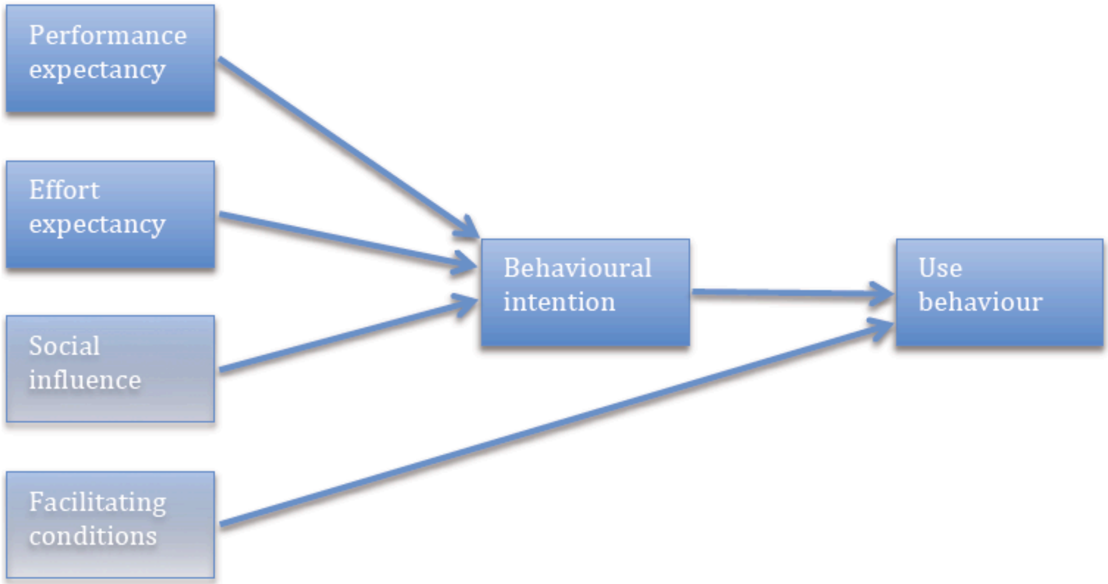

Figure 4. A simplified illustration of the UTAUT model. Adapted from Venkatesh et al. (2003).

Hennington and Janz (2007) also mention the clinicians' perceptions of ease of use regarding the system, which is also described by Venkatesh et al. (2003) as part of *effort expectancy*.

Respect for tradition in working practices

Using *performance expectancy* and *effort expectancy* in the discussion of balancing *tradition* and *transcendence* during the design and implementation of a healthcare information system, I find that a high degree of respect for *tradition* can have a positive effect on both *effort expectancy* and *performance expectancy* since clinicians would not be required to put much effort into starting to use a new but recognizable system or having to readjust existing working practices. The study presented by Niazkhani et al. (2009) is a prime example of a situation where respect for *tradition* regarding the existing working practices has positively affected the users' perceptions of a healthcare information system. In this study, the authors find that nurses accustomed to a workflow similar to the one supported by a new CPOE system (i.e. tradition is preserved) reported more positive effects and were more satisfied than users coming from a very different workflow (i.e. tradition is not preserved). Besides the CPOE system's possible positive effect on *effort expectancy* due to recognizable or intuitive design, I find it reasonable to argue that the increase in satisfaction among the more satisfied nurses could be a result of the similarities between work practices' and thus a positive effect on *performance expectancy* i.e. the more satisfied nurses were more satisfied because the system fitted well with the existing working practices. The results of the studies presented in especially Paper II and VI support the findings of Niazkhani et al. (2009). Here, the relatively high level of satisfaction with the EW system at the four EDs could be attributed to a focus on ensuring that the existing working practices would be altered as little as possible. As Paper VI describes, the EW system was implemented at ED1 and ED2 using an approach that effectively balanced *tradition* and *transcendence*. In this approach gradual adjustments to the existing working practices were performed, which ensured that disruptive changes did not occur and that the clinicians were able to use the EW system without having to adjust to new working practices.

The positive effects of incorporating respect for *tradition* in the design and implementation of a healthcare information system is also underlined by other previous studies, which indicate that too little respect for *tradition* can have a negative effect on the users perceptions such systems. The study presented by Aarts et al. (2004) is a prime example of such a situation. Here, the authors find that resistance towards a CPOE system increased drastically during implementation due to extensive and time consuming changes to the clinicians' working practices caused by a lack of fit between the existing working practices and the new system. In the context of the present discussion, this could be seen as a deviation from *tradition* that negatively affected the clinicians' *performance expectancy*, which ultimately resulted in the total rejection of the CPOE system.

Respect for tradition in system design

This respect for *tradition* is not limited to working practices but is also found in the technical design of some healthcare information systems. As the literature review presented in Paper I finds, the user interface design of many EW systems maintain the same graphical layout as the traditional dry-erase whiteboards – see Figure 1 and Figure 2. As stated in Paper VI this may, among several other possible reasons, be a deliberate choice to foster recognition among the clinicians and thereby reduce the effort needed to learn and understand the new system i.e. *tradition* is preserved through the design of the EW system. Another example of a healthcare system where *tradition* has been sought preserved through the technical design is the EPR system presented by Jaspers et al. (2004). In the design of this system, the authors describe how the clinicians were initially asked to think aloud while reviewing paper-based patient records. The verbal protocols recorded during the think aloud sessions were then used to design the EPR system so that it corresponded "*... to the order in which the pediatric oncologists appeared to seek for and process specific information of the paper-based patient record.*" (Jaspers et al., 2004, pp. 788 – 789). The summative evaluation of the EPR showed that the clinicians generally found the system easy to use and that it conformed to the way they would normally work with the paper-based records. In the context of this discussion, I argue that design choices such as those presented above can be seen as attempts to respect *tradition* and thereby positively affect certain aspects of *effort expectancy* and *performance expectancy*.

Experimenting with transcendence

Notwithstanding the apparent positive effects of incorporating a high degree of respect for *tradition* in the design and implementation of a healthcare information system a focus on *transcendence* is, according to Ehn (1988) and Mogensen (1992), in some cases necessary to advance both the system and working practices, despite the possible negative effects on the clinicians' initial perceptions of the system. Previous research has shown that this is indeed possible if the process of creating *transcendence* is performed in a way that involves the users. Hertzum and Simonsen (2008) describe how an EPR system and the associated working practices were configured and adjusted in a trial implementation at a hospital stroke unit. The resulting system and working practices deviated considerably from the original system and existing working practices. However, an evaluation of the EPR system showed that the clinicians experienced these changes as positive and appreciated the new ways of working.

The same conclusions can be drawn for Bardram et al. (2006). In the design of the EW system presented in this study, the user interface design deviates from the traditional matrix layout and instead incorporates a more cell-based layout that also includes video streaming from cameras placed in operating rooms. These design choices were taken to increase shared awareness regarding the work unfolding at the department. An evaluation showed that the EW system had positive effects on the working practices of the department and that the clinicians appreciated the system. Thus, I find that while a focus on *transcendence* could have a negative impact upon the clinicians' initial perceptions of a new healthcare information system it is in some cases necessary in order to advance the working practices and the technical design.

As a sub-conclusion of this discussion, I argue that while a certain degree of respect for *tradition* is an important aspect of ensuring that clinicians perceive a new healthcare information system positively, experimentation that has a focus on *transcendence* is an important aspect of further improving both organization and information system. This would, for example, allow for experimentation with more extensive changes to working practices and the ability to estimate how they would affect workflow during actual use. Also, such experimentation would enable designers to experiment with alternatives to the existing user interface designs and system functionality. The controlled experiments presented by Anders et al. (2012), Rodriguez et al. (2002), Saleem et al. (2007) and Paper V is one approach to such experimentation. However, since the results of such experiments can be somewhat disconnected from the actual working practices of the intended users it can be hard to apply them directly in the design of either system or working practices. In contrast to this sort of experimentation is the design process described in Paper VI. Here, the initial pilot implementation of the EW system allowed the clinicians to experiment with system under real work conditions. This experimentation included altering the work practices surrounding the system as well as suggesting and implementing changes to the system's user interface and functionality. However, because the experimentation was left primarily to the clinicians it is plausible that the possibilities of the system have not been explored fully and as such there might exist a potential for further improvements in both the system and working practices. The studies presented by Fairbanks et al. (2008), Hertzum and Simonsen (2008) and Li et al. (2012) present a type of experimentation that I would argue contains the best of both the above-mentioned types. In these simulations and trial implementations, researchers and designers can experiment with both the organizational and technical aspects of a healthcare information system under realistic conditions prior to widespread implementation. Thereby, the designers of healthcare information systems have the possibility of investigating how different modifications to organization and system affect users' *effort expectancy* and *performance expectancy* and can perform further modifications to balance these two constructs.

5.2.4 Design and implementation of the electronic whiteboard system

The two design- and implementation approaches described in Papers VI and VII are on a general level very similar. Both have been characterized by the lack of clear and concrete success criteria prior to their initiation, which has necessitated the use of somewhat experimental approaches at the four EDs. Part of these experimental approaches has been an extensive focus on user involvement and user-driven processes during the design and implementation. However, despite these similarities there are certain subtle yet distinct differences that have affected how these processes progressed and how the clinicians at the EDs perceived them. In the following, I will highlight these differences and discuss how they have affected the design and implementation of the EW system at the four EDs.

Fully versus limited sociotechnical design and implementation

The main difference between the two approaches to introducing the EW system is in my opinion the degree to which they adhere to the sociotechnical approach's principle of concurrent organizational and technical development during the design and implementation of information systems (Leonard-Barton, 1988; Berg, 1999). In this context, I would argue that the approach followed at ED1 and ED2 can be seen as being "fully" sociotechnical due to its focus on both organizational and technical development. Through early usage of the system, clinicians were able to provide informal feedback regarding system design and functionality and thereby affect the technical design of the system while development was still progressing. Concurrently, the clinicians had an opportunity to adjust their working practices to take advantage of the new possibilities afforded by the EW system. In this sense the approach followed at these two EDs resembles several of the studies presented in the reviewed literature (Beuscart-Zéphir et al., 2010; Hasvold & Scholl, 2011; Hyun et al., 2009; Paré & Trudel, 2007; Rinkus et al., 2005; Thursky & Mahemoff 2007). I would argue that this approach has enabled a certain degree of iterative experimentation with the EW system and the surrounding working practices, which has led to a relatively harmonious and integrated set of design and implementation processes.

In contrast to this, I would argue that the approach followed at ED3 and ED4 can be described as "limited" sociotechnical. Following the outline of project "Clinical Overview", the EW system was introduced at ED3 and ED4 as a finished but configurable system. This meant that the main focus was on the organizational implementation while technical adjustments were limited to local configurations of the matrix layout. In this sense, the implementation of the EW system at ED3 and ED4 resembled a standard *rollout* of an information system and to some degree the study presented by Peute et al. (2010) and one of the cases described by Paré and Trudel (2007). However, contrary to Peute et al. (2010) and Paré and Trudel (2007) the single sided focus at ED3 and ED4 did not result in the implementation processes being cancelled or severely hampered. It did, however, mean that there was limited room left for experimentation with the technical aspects of the EW system during implementation. As stated by Berg (1999), sociotechnical development includes alterations to both the technical and organizational aspects of a healthcare information system. In light of this, I find it reasonable to suggest that the limited possibilities for technical adjustments and experimentation at ED3 and ED4 has prevented the implementation process from achieving the best possible fit between the work practices and the EW system.

The responsibilities of system champions

The processes of designing and implementing the EW system at the four EDs also differ in their approach to involving the clinicians and the division of responsibility during these processes. As described in Papers VI and VII, local clinicians were involved as system champions at all four EDs. At ED1 and ED2 these champions were involved early in the process of designing and implementing the EW system. Also, they participated in all aspects of these processes as part of the project group and their responsibilities were determined at an early stage. In this sense the approach followed at ED1 and ED2 is very similar to the studies presented by (Hasvold & Scholl, 2011; Hyun et al., 2009; Thursky & Mahemoff, 2007; van der Mejiden et al., 2001). This type of involvement meant that there was little confusion with the involved clinicians regarding the distribution of responsibilities and that if any problems occurred they had the possibility to discuss these with the other members of the project group.

As described above, the EW system was delivered to ED3 and ED4 as a finished but configurable product. Therefore, the system champions at these EDs were chiefly involved in the organizational implementation of the system. Contrary to ED1 and ED2, the champions at ED3 and ED4 were to a higher degree appointed this role. Also, although they were permitted to establish project groups the system champions at ED3 and ED4 worked more individually than their counterparts at ED1 and ED2, who participated as members of Region Zealands project group. They were, however, expected to take on the same responsibility for managing the implementation processes as the champions at ED1 and ED2. This user driven approach was aimed at ensuring that the EW system would be implemented in a way that created a good fit between the working practices of the EDs and the system. In this sense, the approach followed at ED3 and ED4 resembles the study presented by Bossen (2007) and although the implementation of the EW system did not end as dramatically as the process described here (ibid), it did lead to some confusion with the involved clinicians regarding responsibilities for certain aspects of the implementation e.g. acquiring and installing hardware, setting up and configuring the system, etc. In the end, the implementation approach followed meant that the system champions had to struggle with many practical issues during implementation, which *"... did not leave much incentive for extensive technical configurations or innovative experiments with new ways of organizing work."* (Paper VII, pp. 63). Hertzum and Simonsen describe this implementation approach as *"... somewhat laissez faire."* (Hertzum & Simonsen 2012, pp. 9) and find that while the EW system provides some new opportunities these have not been pursued in an organization wide effort. This suggests that the system champions at ED3 and ED4 assumed a less pronounced role during the implementation of the EW system at these EDs.

As a sub conclusion to the above discussion, I find that both design and implementation approaches followed have resulted in the successful implementation of the EW system at the four EDs despite the absence of clear and concrete success criteria. This leads me to suggest that both approaches posses certain specific advantages. For the approach followed at ED1 and ED2, I would argue that the fully sociotechnical development regarding technical and organizational aspects has been the most significant contribution to the successful implementation of the EW system. For the approach followed at ED3 and ED4, I would argue that the locally driven implementation, despite causing some confusion among the involved clinicians, has mitigated the potential drawbacks of the limited possibilities of technical adjustments and has thusly been essential for the successful implementation at these two departments.

5.2.5 Future endeavours: Electronic whiteboards designed in use

In light of the above sub conclusion, I conjecture that a *design in use* or *co-realisation* approach (Dittrich et al., 2002; Hartswood et al., 2003), that combines the fully sociotechnical approach to technical and organizational development from ED1 and ED2 with the locally-driven implementation approach followed at ED3 and ED4, could further enhance the processes of developing and introducing the EW system in future endeavours. In line with Hartswood et al. (2003), I would argue that, by allowing the clinicians the possibility of experimenting with and exploring the technical and organizational aspects of the EW system in the context of their working environment and supporting this experimentation by having IT professionals present, this type of approach has the potential to create an even closer fit between ED's working practices' and the EW system than the previously used approaches.

Designers as users and users as designers

However, I find that there are some aspects of the *co-realisation* and *design in use* methods described by Hartswood et al. (2003) and Dittrich et al. (2002) that complicate the application of design and implementation approaches based on these. Firstly, Hartswood et al. (2003) state *"IT professionals need to 'become users' and appreciate the manner in which artefacts are embedded in workplace contexts."* (Hartswood et al., 2003, pp. 397). However, unless IT professionals actually perform the same work as the users, most IT professionals would probably find it difficult – if not impossible – to fully satisfy this requirement. Also, I argue that it might not be in the best interest of developing and implementing a new information system if IT professionals become too much like the users, since this could distract their attention form matters that would otherwise go unnoticed by the users. Therefore, I find that when following an approach, as the one described above, it is important for the involved IT professionals to find and maintain a balance between viewing the information system through the eyes of the users and their own eyes as the developers of the system.

In a similar vein, Dittrich et al. (2002) state that users of information systems are increasingly becoming important actors in the final design of these systems. Dittrich et al. (2002) term this *shop floor IT management* and argue that organizational support for this sort of information system development should be given in the form of *"... standards, methodologies, modelling languages and other means of representation for cooperative development and – not the least – personnel resources*." (Dittrich et al., 2002, pp. 131-132). This call for increased support for *shop floor IT management* could be seen as a way of enabling the users to become more adept designers of the information system they use. However, in a similar argument as the one stated above, it is not necessarily desirable if the users become too much like designers or IT professionals. Since the power of having users involved in the design of information systems lies in their very nature as users, there is a risk that this uniqueness might be diminished if they become too much like the IT professionals. Therefore, I argue that, despite the importance of having users closely and actively involved in the design of information systems, it is vital that users retain their unique position as users of the information systems being developed.

Who would you have involved?

A second aspect of the *co-realisation* approach described by Hartswood et al. (2003), that I find could complicate the application of this method, is related to the competences of the IT professionals involved. Hartswood et al. (2003) touch upon this subject and state that IT professionals need to expand their current range competences in order to adequately perform the multitude of roles dictated by the *co-realisation* approach. Among others, this includes competences such as "*... design consultant, developer, technician, trouble-shooter and handyman.*" (Hartswood et al., 2003, pp. 395). Besides these, I would argue that IT professionals involved in the development and introduction of healthcare information systems also need to posses competences related to usability evaluations, effect evaluations and organizational change management.

From their description of the *co-realisation* approach, it appears that Hartswood et al. (2003) envision that a single IT professional should be involved throughout the design and implementation of a healthcare information system. For the lightweight approach to development and evaluation suggested by Hartswood et al. (2003) I would agree that the involvement of one IT professional with a wide but possibly perfunctory range of competences might suffice. However, as demonstrated by the results of Papers II-V and the discussions presented in Section 5.2.1, Section 5.2.2 and Section 5.2.3, a lightweight approach to development and evaluation might not be enough to discover more complex and intricate issues regarding both the organizational and technical aspects of health information systems such as the EW system. In situations such as these, I would argue that a deeper knowledge regarding the mentioned competences (e.g. design, evaluation, implementation, organizational change, etc.) is needed. However, I find it unlikely that any one person could posses a deeper knowledge for all the competences mentioned above. Therefore, instead of a single IT professional being involved I would suggest that multiple professionals with different competences are involved when needed during the development and introduction of healthcare information systems such as the EW system.

Co-realizing the development and introduction of the EW system

As a sub conclusion to the above discussion I present an approach to developing and introducing the EW system and healthcare information systems in general, which I argue utilizes the full potential of the *co-realisation* and mitigates the complicating aspect regarding the IT professionals competences. In continuation of the above discussion, I suggest that multiple IT professionals with different competences are involved during the development and introduction of a given system. Due to the sociotechnical nature of designing and implementing healthcare information systems where multiple activities may occur concurrently, it might be necessary to have more than one IT professional involved at a time.

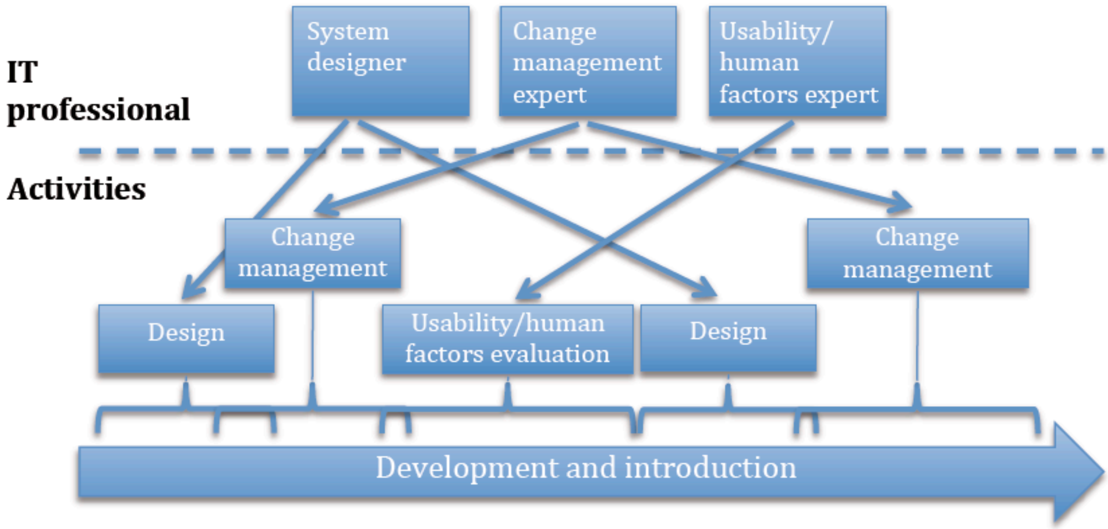

Figure 5. An example of how part of the development and introduction of a healthcare information system could proceed following the proposed *co-realisation* approach.

This could pose a problem for the suggested approach because the presence of a high number of outside personnel might disrupt the working practices of the clinicians. Therefore, I would suggest that no more than two IT professionals should be involved in field-based activities and that on-the-fly replacements are made when necessary e.g. when usability evaluations are needed in order to asses a recent change to the user interface design or when an evaluation of a recent organizational change is required. Figure 5 shows an example of how part of the development and introduction of a healthcare information system could proceed according to the suggested approach. By following this approach, I argue that clinicians are given the opportunity to explore and experiment with the technical and organizational aspects of a new system while receiving support from relevant IT professionals throughout the process of developing and implementing the healthcare information system. This would allow for more thorough evaluations of the new information systems and also enable the clinicians to explore and capture the benefits of emergent and opportunity based changes such as those described by Orlikowski and Hofman (1997).

There are of course some practical aspects of the suggested approach that need to be considered before it can be taken into use. One aspect is who should be in charge of having several IT professionals with a wide range of competences on call and ready to be stationed in different hospital departments within a relatively short time period. One answer to this could be that all hospital departments should have a number of IT professionals with different competences directly employed. However, this would be a very expensive approach and as such this option is not viable for hospital departments. Therefore, I find that a viable solution could be to have the IT professionals located centrally at the local healthcare authority e.g. Region Zealand. Hospitals or hospital departments who feel that they need support from IT professional during the implementation of a healthcare information system can then contact the healthcare authority and have them send out the appropriate IT professional. This would help ensure that the departments receive the relevant support and that the competences of IT professionals are employed efficiently. This approach would also help enable a transfer of experience and knowledge across hospital departments, which the study presented in Paper VII found to be an important aspect during the implementation of the EW system at ED3 and ED4.

Another aspect is how the technical development of a healthcare information system can be kept “alive” throughout the longitudinal process of implementing the system following the *co-realisation* inspired approach described. Without having a clear answer to this, I conjecture that at some point the technical development of the system changes from being focused on developing the system to focus on configuring the system using the available possibilities. However, in continuation of this I argue that the need for having IT professionals available to support the clinicians is not diminished due to such a change in focus. Instead, their role changes along with the change in focus for the overall implementation and as indicated by Hartswood et al. (2003) they take on other responsibilities related to their specific competences.

6 Conclusion

In this cover paper I have presented the background for my PhD, my own studies as well as a general presentation and discussion of the methods applied during the execution of these. Also, I have presented a review of existing literature related to my own studies in order to position my work in relation to these. Finally, through a discussion of the general findings of my research I have related the individual studies to each other and my research as a whole to the existing literature and provided sub conclusions to the discussions. In this concluding chapter I will outline the combined conclusions of these discussions in order to answer the research questions presented in Section 1.5.

From the studies performed, I find that the clinicians generally perceive the EW system as a substantial improvement over the dry-erase whiteboards and report a high degree of satisfaction with the system. This is among other things due to the generally intuitive user interface design and the distributed access to the EW information. Also, the clinicians report that the EW system has made the logistics of the EDs more transparent and visible and generally increased their overview of the departments. In conclusion to Sub Question 1, I find that the EW system's user interface design has not affected the clinicians' perceptions or usage of the system in a negative way. However, the usability evaluations performed showed that the user interface contains some usability issues that if corrected could especially improve the users efficiency with the system. Also, the results of the experiment reported in Paper V showed that the clinicians preferred to work in an individual and sequential manner for some tasks instead of the more common collaborative work practices. The results showed that the user interface design generally supported this type of work well. In conclusion to Sub Question 2, I find that the user-oriented and locally driven approaches to designing and implementing the EW system has led to the implementation of a system that caused only minor disturbances and alterations to the existing working practices. Also, because of an extensive focus on designing an easily recognized user interface the EW system was adopted and taken into use by the clinicians with relative ease. However, the findings of the discussion in this cover paper indicated that more extensive experimentation with the EW system and the surrounding work practices could have been employed in order to further advance both the technical and organizational aspects of the system.

Based on the conclusions of Sub Question 1 and 2, I find that the conclusion to the overall research question is somewhat divided in two according to the goal of developing and introducing an EW system. If the goal is to develop and implement a system that can be taken into use with relative ease and only requires slight changes to the clinicians' working practices then the approach described in Papers VI and VII could be suitable based on the outcome of the approach's application in Region Zealands EDs. However, I argue that if the goal is to significantly improve the working practices and provide a EW system that supports these working practices, more attention should be dedicated to systematic evaluation and experimentation with the technical and organizational aspects of the EW system as well as ensuring that the results of such activities are employed as part of further development efforts. In continuation of this, I find that an approach similar to the *co-realisation* method described by Hartswood et al. (2003) could be a viable approach to creating a truly sociotechnical environment for the development of an EW system. However, the suggested approach deviates from the original *co-realisation* method and recommends that multiple IT professionals with different competences should be involved on a on-call based approach throughout the design and implementation processes. I argue that this will help ensure that the clinicians involved in these processes are able to receive support from relevant IT professionals when it is needed. Also, I find that such an approach would allow the users and designers to explore and evaluate any emergent changes in cooperation and thus a *co-realisation* approach would supplement the improvisational change management that is often associated with the implementation of information systems in organizations (Orlikowski and Hofman, 1997).

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9 Appendix

Paper I: Electronic whiteboards in emergency medicine: A systematic review

Paper II: Consider the details: A study of the reading distance and revision time of electronic over dry-erase whiteboards

Paper III: Digital video analysis of health professionals' interactions with an electronic whiteboard: A longitudinal, naturalistic study of changes to user interactions

Paper IV: The long and twisting path: An efficiency evaluation of an electronic whiteboard system

Paper V: Visualizing the application of filters: A comparison of blocking, blurring, and colour-coding whiteboard Information

Paper VI: Balancing tradition and transcendence in the implementation of Emergency Department electronic whiteboards

Paper VII: User participation in implementation

9 Appendix

Table of appendix

9.1 **Paper I:** Electronic whiteboards in emergency medicine: A systematic review

Electronic Whiteboards in Emergency Medicine: A Systematic Review

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ABSTRACT

As more and more Emergency Departments replace the manual dry-erase whiteboards used for coordination of patient care and communication among clinicians with IT-based electronic whiteboards a need to clarify the effects of implementing these systems arises. This paper seeks to answer this question by systematically reviewing studies on electronic whiteboards. The results of the review indicate that electronic whiteboards influence the work at Emergency Departments in various different ways e.g. changes to work practice and changes to whiteboard information accuracy. Also, the review finds that there are mediating factors that have an impact upon these effects e.g. display format and integration with other clinical IT systems. However, the results are somewhat inconclusive and of a mixed nature and therefore this paper calls for more focused and specific research.

Categories and Subject Descriptors

J.3 [**Life and medical sciences**] – Medical information systems

General Terms

Design, Human Factors, Management

Keywords

Systematic review, healthcare informatics, electronic whiteboards, emergency medicine

1. INTRODUCTION

At most Emergency Departments (ED) the use of a patient tracking and coordination system is critical as well as essential for maintaining a smooth operation of the department [3], [33]. Often, the cornerstone of this type of system is a large dry-erase whiteboard with a matrix-like information structure displaying information regarding the current ED patients. The whiteboard is often placed centrally in the ED and is frequently accessed and manually updated by the ED staff [33], [34]. As such, the whiteboard functions as the central communication and coordination tool for ED clinicians allowing them to retain an overview of the status of individual patients and the department in general as well as allowing clinicians to pass information on to their colleagues [34]. Previous research has shown that these types of systems play a vital role in facilitating communication between ED staff and coordinating care for the ED patients. As a result of this, they have become an integrated part of the working practices of EDs and hospital departments in general [19], [34], [37]. These systems have achieved such a central role due to their ability to function as effective and efficient coordination and communication artifacts despite the unpredictable and chaotic working environment that characterizes many EDs [37].

Recently, EDs in Europe and the U.S.A have started to replace these manual patient tracking and coordination systems with IT-based systems for a number of different reasons [3], [7]. With an increase in popularity of these IT-based patient tracking and coordination systems, known as electronic whiteboards, a need for summarizing the type of effects that can be expected to occur when implementing these systems has arisen. This study will seek to fulfill this need by systematically reviewing the published literature on studies of electronic whiteboards used in emergency medicine.

2. RESEARCH QUESTION

In this study the following two research questions are addressed:

RQ1. What consequences does introducing and using electronic whiteboards have on ED work?

RQ2. What mediating factors influence these consequences?

RQ1 is the main research question for this study. However, the reviewed literature indicates that there are several mediating factors that may influence what effects an IT-based electronic whiteboard system may have. These factors include the format in which the electronic whiteboards present information, the integration to other clinical IT systems, the visual layout and interface design of the electronic whiteboards and finally the process of developing and implementing these systems. RQ2 addresses these factors.

3. METHOD

The study reported in this paper has been conducted as a systematic literature review based on the guidelines proposed in Kitchenham et al. [17]. The aim of the review is to gather knowledge regarding the effects of implementing electronic whiteboards in emergency medicine. As such, the current study can be categorized as a secondary study.

3.1 Search process

The literature search process was a four-step process designed to cover as much literature as possible. Initially, three automated searches were conducted using Google Scholar, ISI Web of Science and PubMed with the keywords "Emergency department*", "Clinical overview", "Medical informatics" and "Healthcare informatics" combined with the following search terms: "Electronic whiteboard*", "computerized whiteboard*", "status board*" and "tracking board*". The asterisk after each search term indicates that any inflection of the word is accepted in the search results. The author perused the titles in the search results and based on this, articles that were found to be relevant were saved for further reading. After having filtered through the initial search results the abstracts of the saved articles were read to further filter and refine the results. Based on this a selection of articles was saved for a full reading.

Following the automated searches a journal specific search was conducted in the following six journals:

- International Journal of Medical Informatics
- Journal of the American Medical Informatics Association
- Journal of Emergency Nursing
- Journal of Emergency Medicine
- International Journal of Human-Computer Interaction
- ACM Transactions of Human-Computer Interaction

The selection of the above journals was conducted as a two-step process. First, a list of approximately 21,000 international journals was searched for journals relevant to the topics of this study. From this list a selection of 20 internationally recognized journals was made and out of these the selected six were chosen on the basis of a reading and evaluation of their scope and aims. This was done to ensure a fit between the research questions and the content of the journals. The last two journals on the list were included in order to find articles published in journals that do not have a specific focus on medical informatics or emergency medicine. The journal specific searches were carried out manually in order to ensure that the shortcomings of an automated search did not affect this search, i.e. using words when searching for concepts. In order to limit the amount of material to filter, the manual searches were limited to cover only a period of six years from 2005 to 2010. Again, the titles of the journal articles were used as the first filter and following this the abstracts of any saved articles were read. If an abstract indicated that an article might be relevant for the review the full article was selected for further reading.

Next, the references of the already selected articles were perused for relevant articles that had not been found during the previous steps. Finally, a search on ISI Web of Knowledge was conducted to find articles that referred to the already selected articles. The combined search process led to a selection of 20 articles plus one that was sent to the author by a colleague after having completed the search process.

3.2 Inclusion and exclusion criteria

During the search process the following inclusion and exclusion criteria were applied. Based on a reading of article abstracts, full articles in English on one or more of the following topics were included in the literature review:

- Evaluation of the effects on work practices caused by electronic whiteboards.
- The process of developing and implementing electronic whiteboards.
- Description of the interface design of electronic whiteboards and integration with other systems
- Theoretical aspects of designing, developing, implementing and using electronic whiteboards.
- Combinations of the above topics.

Articles that did not fulfill the stated inclusion criteria were excluded from the literature review. This included papers such as:

- Articles without relevance to any of the above stated topics
- Conference abstracts
- Letters to the editor or editorials
- Duplicates or near identical papers

Table 1: Search results

Search type	Number of articles
Automatic	16
Manual	2
References of found articles	1
ISI search for articles referring already found articles	1

Table 1 shows the results of each step in the search process after having applied the inclusion criteria.

3.3 Quality assessment

The articles selected for the study were evaluated according to the type of paper using a ranking system reflecting the following:

- Journal articles/book chapters
- Conference articles
- Practitioners reports

Also, the articles were classified according to the type of study reported on in the paper. This was done using a classification system similar to the one used by Wiler et al. [35]. However, this classification was not used in an assessment of the quality of the selected articles.

3.4 Data collection and analysis

Data was collected from the selected articles via a thorough reading of the articles and writing a summary of the contents. Besides the summary the following data were also extracted from the articles:

- The source and full reference
- Author(s)
- Study category
- Methods
- Main topic
- Setting
- Relevance to the two research questions
- Quality assessment

After having extracted the data from the selected articles, a selection of these data was tabulated in order to present an overview of the selected literature.

4. RESULTS

Table 2 shows the selected articles and displays information regarding the setting for the different studies, the type of studies, the methods employed, the topics of the studies and finally an assessment of quality. In the following the results shown in table 2 will be related to the two research questions in order to allow a discussion of the results. Since a number of the articles relate to more than one of the research questions, these articles will be discussed more than once in the following sections.

4.1 General description of results

As table 2 shows, the majority of the articles reviewed are either single- or multi-site case reports. This appears to be the dominant type of literature within the chosen research area, possibly because it can be difficult to carry out controlled experiments using specific metrics in the setting of ED's. As such, these are the circumstances, under which the review has been preformed.

It is often argued that case reports sacrifice reliability and generalizability in order to achieve a higher degree of realism of context in their results [20]. In this sense it could be argued that the strength of evidence of the selected articles is limited.

Table 2: Reviewed studies.

Reference/year	Setting	Type	Method	Topic(s)	Quality assessment
Abujudeh et al. (2010) [2]	Emergency radiology department, approx. 101,000 examinations pr. year	Single site Case report	Descriptive/not reported	Dry-erase vs. electronic whiteboards, system description, effects on work practice	Journal article
Aronsky et al. (2008) [3]	Adult and pediatric emergency departments	Multi site Case report	Descriptive/not reported	Dry-erase vs. electronic whiteboards, system description, effects on ED work	Journal article
Bardram et al. (2006) [4]	Operating ward at hospital	Single site Case report	Descriptive/not reported	Development considerations, system description, technical implementation, system usage	Conference article
Belser et al. (2005) [5]	Emergency department	Single site Case report	Descriptive/not reported	Implementation and development considerations	Book chapter
Bisantz et al. (2010) [7]	Emergency department, approx. 95,000 visits pr. year	Single site Case report	Photography	Dry-erase vs. electronic whiteboards, changes to information content	Journal article
Boger (2003) [8]	Emergency department	Single site Case report	Descriptive/not reported	Implementation considerations, effects on length of stay for patients, patient satisfaction	Practitioners report
Fairbanks et al. (2008) [10]	Emergency department, approx. 95,000 visits pr. year	Single site Controlled trials	Observations, simulations, field notes	Usability testing of a electronic whiteboard system	Conference article
France et al. (2005) [11]	Adult emergency department, approx. 43,000 visits pr. year	Single site Case report	Observations, system workload, TLX ratings, pedometer	Effects on clinicians behaviors and workload	Journal article
Gorsha and Stogoski (2006) [12]	Emergency department, approx. 30,000 visits pr. year	Single site Case report	Descriptive/not reported	Installation, implementation, evaluation	Practitioners report
Hertzum and Simonsen (2010) [14]	Two emergency departments & one pediatric department	Multi site Survey	Online survey	Clinicians' expectations towards a electronic whiteboard system	Conference article
Horak (2000) [15]	Emergency department	Single site Case report	Descriptive/not reported	Development and implementation considerations	Practitioners report
Jensen (2004) [16]	Hospital inpatient operating rooms and day surgery center	Single site Case report	External consultancy report	Benefits of implementing a patient status and tracking system	Practitioners report
Nicholls and Young (2007) [21]	2 hospitals	Multi site Case report	Descriptive/not reported	Geographical layout used as interface for a bed/patient tracking system, development considerations	Journal article
Patterson et al. (2010) [22]	Two emergency departments, approx. 22,500 visits pr. year	Multi site Case report	Observations	Compare extent of usage, information accuracy and functions for dry-erase and electronic whiteboards	Journal article
Pennathur et al. (2007) [23]	Two emergency departments	Multi site Case report	Observations, photography	Effects on work practices	Conference article

Continues

Continued

Reference	Setting	Type	Method	Topic(s)	Quality assessment
Pennathur et al. (2008) [24]	Emergency department, approx. 95,000 visits pr. year	Single site Case report	Photography	Dry-erase vs. electronic whiteboards, changes to information content	Conference article
Potter (2005) [25]	Emergency department	Single site Case report	Descriptive/not reported	Design, development and implementation considerations, implementation strategy, effects on length of stay and triage times	Practitioners article
Rasmussen et al. (2010) [26]	Two emergency departments	Multi site Case report	Observations, interviews	System description, implementation considerations, effects on work practice	Conference article
Wears et al. (2003) [32]	Four emergency departments	Multi site Case report	Observations, photography	Effects on work practices cause by the differences between dry-erase and electronic whiteboards with regards to: Interface design, information content, language and usage.	Conference article
Wong et al. (2009) [36]	General Internal Medicine department	Single site Case report	Descriptive/not reported	Development and implementation considerations, system description, effects on work practices	Journal article
Zimmerman and Clinton (1995) [38]	Emergency departments, approx. 95,000 visits pr. year	Single site Case report	Descriptive/not reported	Prescriptions for designing computerized tracking, triage and registration systems	Practitioners report

However, I would argue that realism of context is important for understanding some of the unique work practices of the different settings, in which the studies have been performed. Therefore, I argue that for the purpose of this review the lack of generalizability and reliability does not subtract from the strength of evidence and that the selected articles are suitable for the review.

4.2 Consequences of electronic whiteboards

The reviewed literature contains examples of different types of consequences for ED work caused by electronic whiteboards. Table 3 summarizes these consequences and the articles that discuss the specific types of consequences. It should be noted that even though these consequences are discussed separately they are in fact interrelated in many ways e.g. changes to information content on the electronic whiteboard is related to the task of coordinating patient care.

One of the most prevalent consequences reported is that electronic whiteboards affect existing working practices at EDs. Here, the reviewed literature presents mixed results with five articles reporting positive consequences of electronic whiteboards on working practices, two reporting negative consequences and one that does not differentiate between positive and negative consequences. Also, the literature indicates that these consequences often affect workflow, alter the characteristics of the work carried out and decreases interruptions of patient care work. Abujudeh et al. [2] and Aronsky et al. [3] both describe cases where alterations aimed at improving and simplifying the ED workflow were successfully incorporated in the implementation strategies for the electronic whiteboards. On the other hand, Pennarthur et al. [23] observed that the electronic whiteboard system had a negative impact on the working practices. This was caused by the system's inflexibility and thereby lack of support for parts of the workflow where system flexibility was considered important e.g. triage and patient tracking. Rasmussen et al. [26] report on an implementation process, in which a gradual approach to implementing and developing the electronic whiteboard was followed. This allowed the clinicians and project group to alter both the system and working practices iteratively and concurrently, thereby avoiding any dramatic or negative effects on the existing working practices.

Wears et al. [32] and Wong et al. [36] provide examples of how an electronic whiteboard system changes the characteristics of the work done at EDs. Wears et al. [32] observed that due to the format in which the electronic whiteboard presents the contained information the work practice lost its collaborative nature and turned to be more individualistic. Contrary to this, Wong et al. [36] describe how an electronic whiteboard system helped a general internal medicine department transform their discussions regarding discharge planning from being unstructured to be a structured process that drives discussion and increases transparency.

Finally, Abujudeh et al. [2], France et al. [11] and Bardram et al. [4] find that the rate of interruptions and unnecessary communications is reduced after the introduction of an electronic whiteboard system, thus improving the quality of care and the ED work in general.

Table 3: Different types of consequences.

Type of consequence	Positive	Negative	Neutral
Changes to work practice	[2]; [3]; [4]; [11]; [36]	[23]; [32]	[26]
Effects on communication and coordination	[2]; [3]; [36]	[7]; [23]	
Changes to whiteboard information content, language and accuracy		[7]; [22]; [24]; [32]	
Changes to whiteboard role and usage		[7]; [22]; [24]; [32]	[26]
Clinicians' perceptions, attitudes and satisfaction	[11]; [14]; [36]		
Effects on patient care e.g. general patient satisfaction, patient safety, length of stay etc.	[8]; [16]; [21]; [25]	[10]	
Effects on financial and administrative aspects	[3]; [16]		

The communication and coordination between ED clinicians is also influenced by the introduction of electronic whiteboards. This aspect is closely related to the effects on working practice since communication and coordination obviously constitute significant parts of the work performed in an ED. However, since the electronic whiteboards are often referred to as tools for coordination and communication this aspect is discussed separately. Again, the reviewed literature presents mixed findings indicating that electronic whiteboards can have both positive and negative consequences for this aspect of ED work. Abujudeh et al. [2], Aronsky et al. [3] and Wong et al. [36] present results indicating that electronic whiteboards have a positive influence on the communication among ED clinicians. However, Pennarthur et al. [23] find through their observations that the electronic whiteboard had a negative impact on the intradepartmental communication due to the lack of a common discussion artifact. The literature also presents mixed findings regarding how electronic whiteboards influence the coordination of work and patient care at EDs. Abujudeh et al. [2] and Wong et al. [36] both state that the introduction of an electronic whiteboard system has enhanced the coordination between ED clinicians. This is reported to be caused by several features of the electronic whiteboards e.g. distributed access to whiteboard information, quick and easy access to relevant information, the ability to retrieve previously saved information etc. However, the results presented in Pennarthur et al. [23] and Wears et al. [32] point in the opposite direction. In these studies the authors observe that the electronic whiteboards had negative effects on coordination between clinicians. The negative effects on communication caused some of these effects while others were caused by system deficiencies e.g. system properties that allowed only three lines of text to be shown in comment fields and the system's lack of support for other input than text, e.g. symbols and domain specific codes.

The reviewed literature provides examples of how the transition from manual to electronic whiteboards has changed the information content of the whiteboards, the accuracy of the information and the language used on the whiteboards. Generally, the literature reports that the electronic whiteboards are less effective for providing information related to the coordination of patient care [7], [22], [24], [32], that they contain unique information relevant for administration purposes [7], [32], that the information presented by these systems is less accurate than the manual systems [22] and that the language used in the electronic whiteboards is less flexible than in the manual systems [32].

Bisantz et al. [7], Pennarthur et al. [24], Patterson et al. [22] and Wears et al. [32] find that the manual and electronic whiteboards to some degree contain the same core information e.g. arrival time, patient identification, chief complaint etc. However, they also find that there are certain differences between the two types of systems. For example, Bisantz et al. [7] and Pennarthur et al. [24] find that the manual whiteboards contain more information related to the coordination of patient care while Wears et al. [32] and Patterson et al. [22] observe that the manual whiteboards are more effective for relaying extra information by allowing the usage of special shorthand symbols. On the other hand, the findings presented by Bisantz et al. [7] and Wears et al. [32] show that the electronic whiteboards contain information unique to this type of system. This information includes calculated length of stay, automatic flagging of information, census information and number of patients waiting.

Wears et al. [32] also study the differences in language used in the two types of whiteboard systems. Here, they observe that each ED in their study has developed an agreed upon language for displaying information. However, they also find that when this language is codified in the electronic system it becomes static and inflexible. Compared to the manual whiteboards this is a disadvantage of the electronic systems because real-time additions and customizations are not easily made. A part of the study reported in Patterson et al. [22] concerns the accuracy of the information shown by manual and electronic whiteboards. Here, the findings show that the electronic whiteboards contain more errors and types of errors than the manual whiteboards.

The reviewed literature also studies what changes to role and usage occur when transitioning from manual whiteboard systems to the electronic whiteboards systems. Again, the literature presents mixed results. Three articles report that the role of the electronic whiteboards is mostly an administrative one [7], [22], [32], one article reports that the electronic whiteboard system is used for the same purposes as the manual system [26] and three articles report that the electronic whiteboards are used less frequently than the manual systems [7], [22], [24].

Patterson et al. [22] and Wears et al. [32] compare the functions of manual and electronic whiteboards and find that the manual whiteboards are used more often for tasks related to coordination of patient care than the electronic whiteboards. Concurrently, Patterson et al. [22] observe that the electronic boards are mostly used for administrative tasks e.g. collecting data for reporting purposes. Bisantz et al. [7] support this finding by stating that after the ED whiteboard in their case was computerized, its role changed from being a tool for communication and coordination between ED clinicians to a tool for tracking support functions and communication between ancillary ED staff. Somewhat contrary to these findings, Rasmussen et al. [26] find that the electronic whiteboards in their case are used in the same manner as the manual whiteboard thereby retaining its role as a tool for coordination and communication among ED clinicians.

The literature offers examples of how the usage of the ED whiteboard changes when transitioning from a manual to an electronic system. Here, the literature indicates that manual whiteboards are used in a more dynamic manner than the electronic whiteboards [7], [24] and Patterson et al. [22] observe that the physicians in their case were more reluctant to use the electronic whiteboard system than the manual dry-erase whiteboard.

The reviewed literature also gives some insight as to how the clinicians perceive the electronic whiteboards. In this case, the results indicate that the clinicians are generally positive toward the electronic whiteboards. For example, Wong et al. [36] report that even though their survey shows that physicians were less satisfied there was an overall satisfaction with the electronic whiteboard system in the ED. Also, the mental workload scores (rated on the TLX scale) reported by France et al. [11] indicate that the electronic whiteboards can improve the distribution of workload amongst resident and faculty physicians. Finally, the survey results reported by Hertzum and Simonsen [14] show that the ED clinicians in this case have positive expectations towards the introduction of an electronic whiteboard and that they expect the electronic whiteboards to be beneficial for their working practices.

Another consequence for ED work when introducing electronic whiteboards is the effect this has on patient care e.g. general patient satisfaction, patient safety and length of stay. These effects are mostly reported in practitioner's reports such as Boger [8], Jensen [16], Nicholls and Young [21] and Potter [25] who all find that the introduction of an electronic whiteboard system reduces patient length of stay. Furthermore, Boger [8], Jensen [16] and Potter [25] find that the electronic whiteboards helped reduce the number of patients who left the department without "being seen". Finally, Boger [8] and Jensen [16] find that patient satisfaction increased after introducing an electronic whiteboard system at the respective EDs.

It is also likely that patient safety may be affected by the introduction of electronic whiteboards. One issue that could influence patient safety is the usability of these systems as investigated by Fairbanks et al. [10]. Here, the authors find that the interface of the electronic whiteboard system in their case has many flaws in terms of the usability principles applied in their trials. As a result of this the authors speculate that these flaws could have potential negative effects on patient safety and therefore encourage the purchasers of the electronic whiteboard to consider these issues when purchasing the system in question.

Finally, the reviewed literature also presents consequences that relate to the administrative and financial aspects of ED work. Here, the literature indicates that electronic whiteboards have a positive influence on both of these aspects. Aronsky et al. [3] find that the electronic whiteboard system supports many of the administrative processes related to the operation of an ED e.g. daily and monthly reporting, providing educational feedback and impact assessment of improvement initiatives.

Table 4: Mediating factors

Mediating factor	Articles
Presentation format	[2]; [3]; [4]; [7]; [8]; [11]; [15]; [22]; [23]; [25]; [26]; [32]; [36]
Integration	[2]; [3]; [5]; [22]; [32]; [36]
Interface design	[2]; [3]; [4]; [5]; [7]; [10]; [15]; [21]; [22]; [23]; [24]; [25]; [26]; [32]; [36]; [38]
Development and implementation	[4]; [5]; [8]; [12]; [15]; [21]; [25]; [26]; [36]; [38]

Aronsky et al. [3] also report that the electronic whiteboard system had financial benefits for the ED mainly due to an improvement of the discharge process leading to a 2 % increase in posted charges, which translated to additional revenue in excess of $1 million. These results are supported by the findings presented in Jensen [16], stating that the ED in their case experienced multiple financial benefits caused by improvements to a number of aspects to the ED work e.g. reducing the number of patients who leave the ED without "being seen".

4.3 Mediating factors

When reviewing the literature it becomes apparent that there are several mediating factors that could influence how the introduction of an electronic whiteboard system affects the work at Emergency Departments. In this section a number of these factors will be highlighted and exemplified with parts of the reviewed literature. Table 4 summarizes the mediating factors.

One of the clearest mediating factors is the format in which the electronic whiteboards present the contained information. Three of the 13 articles that mention the display format state that the electronic whiteboards are not displayed in a large format and that they are accessed through individual workstations. All of these articles report negative effects on different aspects of ED work. Work practices, communication and coordination seem especially affected by the lack of a large display format [32], [23]. Furthermore, it is likely that the change in function towards an administrative tool, as reported by Patterson et al. [22], is influenced by the lack of a large format display. It should be noted though that not all problems with electronic whiteboards are caused by lack of large format displays. In the study performed by Fairbanks et al. [10] the usability problems discovered here are unrelated to the fact that the electronic whiteboard information is displayed in a large format. Similarly, the changes and loss of critical information as reported by Bisantz et al. [7] are unrelated to the information being displayed in a large format. However, it does seem apparent that there must exist some relation between the successful use of an electronic whiteboard and displaying the contained information in a large format. This becomes apparent when reading the remaining eight articles that all report successful usage of electronic whiteboards and presenting information in a large format [2], [3], [4], [11], [15], [25], [26], [36].

Another mediating factor in the literature is the integration between the electronic whiteboard system and other clinical IT systems. As pointed out by Abujudeh et al. [2], an electronic whiteboard system with manual data entry and updating is no more accurate than the people who enter information into the system. Also, there is an extra time-consuming work burden associated with the entry and updating of information that could hinder effective usage of an electronic whiteboard system. These drawbacks could be reduced by extracting information from other clinical IT systems, e.g. electronic medical records and computerized provider order entry systems [2], [22]. Aronsky et al. [3] provide a thorough description of how an electronic whiteboard can be integrated with a wide range of clinical IT systems and how this provides its users with *"an indispensable tool to access patient-specific information, coordinate patient management, track individual patient care, and monitor overall ED operations in real time"* [3], p. 192]. Belser et al. [5], Wears and Perry [32] and Wong et al. [36] also find that the integration between the electronic whiteboards and clinical IT systems such as patient registration systems, laboratory/x-ray systems and clinical information systems is beneficial for the users of the electronic whiteboards. Thus, is seems that widespread integration with other clinical IT systems is an important factor to consider when introducing electronic whiteboards.

A third mediating factor that could potentially have an impact on how electronic whiteboards influence ED work is the user interface design of these systems. When reviewing the selected literature it becomes apparent that there have been no significant changes to the basic visual layout when transitioning from the dry-erase to the electronic whiteboards. Aronsky et al. [3] describe the layout of the electronic whiteboard in their case as *"much like a real time interactive spread sheet"* [3], p. 185]. The description of the visual layout as a tabular information structure is repeated in 14 of the 16 articles that either describe or present examples of the user interface [2], [3], [5], [7], [10], [15], [22], [23], [24], [25], [26], [32], [36], [38]. Only two articles describe interface designs that deviate from the tabular information structure. Bardram et al. [4] describe an electronic whiteboard system designed to support awareness, coordination and communication in an operating ward. Here, the interface design consists of a more dispersed layout showing different interface elements such as an overview of the staff on duty, a scheduling tool and video feeds from different rooms in the ward. Nicholls et al. [21] describe an even more radical approach to designing the visual layout of an electronic whiteboard used for tracking patients. Here, the user interface design is inspired by geographic information systems and thus, the visual layout is a geographical reproduction of the ward showing rooms and bed locations.

However, due to the widespread use of the traditional visual layout of the user interface it is difficult to draw any conclusions from the literature as to whether or not the interface design of electronic whiteboards has any effect on how these systems influence ED work. This point will be revisited in the discussion of the results.

Finally, the process of developing and implementing electronic whiteboards seems to be another mediating factor that influences the consequences for ED work when introducing this type of system. This seems apparent since the type of development and implementation process followed has a strong influence on how new IT systems are received in organizations.

Six of the reviewed articles include descriptions of development and implementation processes and also include descriptions of the consequences of using the electronic whiteboards [4], [8], [21], [25], [26], [36]. Another four articles describe only the development and implementation processes but do not couple these to the consequences of introducing the electronic whiteboards [5], [12], [15], [38]. Common to most of the studies in the abovementioned literature is a strong focus on a user-centered approach to both the development and implementation of the electronic whiteboards e.g. user involvement in all parts of the processes, extensive user training as well as support for the users.

User involvement is highlighted as critical for the successful development and implementation of electronic whiteboards. This is well exemplified by the studies reported in Potter [25] and Rasmussen et al. [26]. In general, the reviewed literature presents examples of user involvement in which a few participants are involved as representatives of the larger group of end-users. Belser et al. [5] and Wong et al. [36] are examples of how administrative staff members have been involved as representatives for the future users while Horak [15], Potter [25] and Rasmussen et al. [26] are examples of how clinical staff members have been involved in developing and implementing electronic whiteboards.

The reviewed literature also highlights user training as an important aspect of implementing electronic whiteboards. This is exemplified in Boger [8] and Potter [25] where training was tailored to suit each staff group in the ED. In the case described in Horak [15] this was taken one step further and included individual training for all ED staff members.

User support in the initial phases of electronic whiteboard usage is also pointed out as an important part of the implementation processes. Horak [15] and Potter [25] present cases where this support was provided by developing support manuals for the ED staff. Wong et al. [36] describe another approach where technical personnel provided on-site support for two weeks after implementing the electronic whiteboard.

Interestingly, these articles do not reveal which type of user involvement, user training or type of support work is preferable as they all report successful implementation and usage of the electronic whiteboards.

5. DISCUSSION

As section 4.2 and 4.3 have shown, the results found in the review are of a mixed and somewhat inconclusive nature. Consequently, this makes it difficult to draw conclusions based on the results. However, the results are relevant for pointing out areas of interest where more research is necessary for clarifying the consequences of implementing electronic whiteboards. These areas will be pointed out in the following sections.

5.1 General discussion of results

Existing work practices including coordination and communication is one aspect of ED work that seems to be especially affected by the introduction of electronic whiteboards. This is not surprising since the manual whiteboards, which the electronic whiteboards are intended to replace, constitute a vital artifact for these practices. The results of this study show that the electronic whiteboards have both positive and negative consequences for working practices of EDs.

The results suggest that electronic whiteboards have negative consequences for whiteboard information content, information accuracy, the language used and whiteboard functionality after implementing electronic whiteboards. It is particularly interesting to note that the electronic whiteboards have a tendency to reduce the accuracy of the information presented and that the role of the whiteboard changes from a tool used for coordination and communication among the clinicians to a tool mostly used for administrative purposes.

Positive results were found in studies with a focus on patient related aspects such as patient satisfaction and length of stay as well as financial and administrative aspects. The shift in role for the electronic whiteboards, as mention above, corresponds well with these advantages for the administrative aspects of ED work.

The results showed that the clinicians generally had high expectations to the electronic whiteboards and that they perceive them to support and enhance their work practices. The studies that investigate these aspects are all in one way or another based on the clinicians' subjective evaluations and as such they are vulnerable to variations due to the clinicians' personal feelings towards the system. An interesting pattern emerges when the results of these studies are compared to the results of the other reviewed studies. The pattern shows that the studies based on the clinicians' subjective perceptions and attitudes are all predominantly positive while the other studies show results of a more mixed nature. One possible reason for this pattern could be a mismatch between what is measured by the researchers in the more objective studies and the factors that shape the clinicians' attitudes and perceptions of the system. In a sense, this means that if the researchers' measurements do not concern the aspects of the electronic whiteboards that matter to the actual end-users, the results might not reflect their attitudes towards the electronic whiteboards. On the other hand, it is also possible that the studies based on the clinicians' attitudes and perceptions, show these predominantly positive results simply because the researchers and subjects interacted during the investigation. This is known as demand characteristics or interpersonal expectancy effects and may influence the results of such studies [29], [30]. It seems reasonable to assume that such effects could have influenced the results of the studies that are based on the clinicians' subjective attitudes and perceptions towards the electronic whiteboards. This must therefore be taken into consideration when interpreting the results of studies that utilize methods through which the researcher could possibly influence the participants, e.g. surveys, interviews, etc.

5.2 Discussion of mediating factors

The mediating factors presented in Section 4.3 can be divided into two groups of factors: System specific factors and general factors.

5.2.1 System specific factors

The first three factors (display format, integration and interface design) can be categorized as system-specific factors since they concern different parts of the particular systems in the different studies. Since the results of the review suggest that these factors have an influence on how the end-users perceive and adopt the electronic whiteboards, they will be discussed in the following using the Unified Theory of Acceptance and Use of Technology (UTAUT) model as presented in Venkatesh et al. [31].

As mentioned in section 4.3 one of the mediating factors found in the reviewed studies is the format in which the electronic whiteboards present information. As the results suggest, there seems to exist a relation between using large format displays and the successful implementation of the electronic whiteboards. A reasonable explanation for this relationship is that the clinicians are accustomed to using a display format that can be easily viewed and scanned for information without necessarily having to interact with the system itself e.g. the large manual dry-erase whiteboards [37]. Following the transition to the electronic whiteboards the clinicians might expect to be able to maintain this working practice, which however only seems possible if a large and easily viewed display is used. If this is not the case, the clinicians will have to log onto a computer terminal every time they want to retrieve information from the electronic whiteboard. If this leads the clinicians to perceive the system as less efficient and more laborious to use an increase to the users effort expectancy and a decrease to their performance expectancy might result. According to Venkatesh et al. [31], the users' performance expectancy and effort expectancy have a high impact on their perception of the system. A negative impact on these constructs will therefore decrease the likelihood of the system being accepted by the users and thereby reduce the probability of a successful implementation process. The relationship between display format and successful implementation is however not investigated in detail by the reviewed literature and presents an area of interest for conducting more research.

The results of the review also suggest that there is a positive relationship between a successful implementation and widespread integration between the electronic whiteboards and other clinical IT systems. One reasonable explanation for this relationship is that this integration provides the clinicians with new opportunities compared to the old dry-erase whiteboards e.g. retrieving patient information from electronic health records or automatic notification of lab results. As such, the clinicians could perceive the electronic whiteboards as being able to help them attain gains in their work. According to Venkatesh et al. [31], this will have a positive influence on the users performance expectancy and thereby increase the likelihood of the system being accepted. On the other hand, it also seems likely that the lack of integration between electronic whiteboards and other clinical IT systems could have a negative impact upon the users' effort expectancy. This seems reasonable to suggest, since the lack of integration would result in the clinicians having to manually enter information into the electronic whiteboards thus increasing the effort and complexity of using the system. According to Venkatesh et al. [31], this will reduce the likelihood of the users accepting the system and thereby the probability of a successful implementation. However, once again the reviewed literature does not contain any studies that specifically investigate these relations and as such there is a need and opportunity to conduct more research in this area of interest.

The third system specific mediating factor concerns the interface design of the electronic whiteboards. As the results in section 4.3 showed there have not been any significant changes to the visual layout of the whiteboards after the transition from the manual to the electronic versions. As Rasmussen et al. [26] find in their study, this could be an explicit choice in the development process to ensure compatibility and recognition when shifting from the dry-erase to the electronic whiteboards in order to ease the transition. This will in turn have a positive impact on the users' effort expectancy since they are not required to adapt to a new visual layout. However, it seems reasonable to argue that this layout offers few new possibilities for the clinicians and as such the interface itself does not add to the users' performance expectancy. Therefore, the choice to keep the interface design from the manual whiteboards can be seen as a short-term prioritization of effort expectancy over performance expectancy. According to Venkatesh et al. [31], performance expectancy is the strongest predictor of the users' intention to adopt and use an IT system. Effort expectancy is also a strong predictor in the early stages of using a new system but becomes less significant after periods of sustained usage. Following this line of argumentation, it would seem that the positive long-term effects of introducing a user interface with new possibilities and better support for the clinicians' work would supersede the short-term effects of having a recognizable user interface. However, since the reviewed literature does not reveal what effects the user interface has on the users' usage of electronic whiteboards it is difficult to draw any conclusions regarding the possibilities for improving the visual layout of electronic whiteboards.

5.2.2 Development and implementation factors

The fourth mediating factor is of a more general nature than the three discussed previously and concerns the manner, in which the electronic whiteboards are developed and implemented – including user training and support. As the results in section 4.3 show there is a strong focus in the reviewed literature on having a user-centered approach. This factor can be seen in the light of the theories regarding user participation in IT development and implementation projects. User participation in IT projects, as defined by [9], [13], is often heralded as an important part of achieving a fit between the system, the users' needs and the context of use [18]. This fit is especially important in complex working environments such as EDs, where previous research has shown that developing and implementing usable IT systems can be a challenging and complex process [1], [6]. Therefore, it appears essential that users participate in the development and implementation of the electronic whiteboards.

However, there are certain difficulties associated with the involvement of users in such projects. As the results in section 4.2 suggest, the new electronic whiteboards have the ability to support a wider range of working practices than the manual dry-erase whiteboards did e.g. communication and coordination for the clinical personnel as well as storing and retrieving information for administrative purposes. This is also evident from the results showing that the electronic whiteboards assumed a more administrative role than the manual whiteboards. These changes will in effect expand the group of potential end-users since this group no longer consists of only the clinical ED personnel but also management and ancillary staff members. This expansion of the end-user group has consequences for the processes of developing and implementing the electronic whiteboards since more interests and work practices need to be considered during these processes. As previous research has shown it can be difficult to manage and actively involve larger groups of participants in IT development and implementation projects [1]. Therefore, it is often decided to involve only a few users as representatives for the entire group of end-users [27]. This pattern is also evident from the reviewed articles that describe the manner of user involvement. However, with the expansion of the end-user group it not only becomes more difficult to select the right participants but it also increases the difficulty of undertaking the task as an effective user representative. This increase occurs because higher demands are put on the participants' professional and personal competences e.g. a broader range of domain knowledge as well as an empathy and understanding of needs and wishes from a large group of users [27]. Therefore, it appears important to consider carefully which users are chosen as participants when developing and implementing electronic whiteboards for use in EDs.

6. CONCLUSION

Different aspects of electronic whiteboards have been investigated in 21 different studies and this systematic review has shown that the electronic whiteboards affect the work performed at EDs at multiple levels e.g. working practices, coordination and communication, information content and information accuracy. The review has also shown that there are several mediating factors that have an impact upon the effects of implementing electronic whiteboards in Emergency Departments. These mediating factors contribute to how the end users perceive the electronic whiteboards and therefore they are instrumental in securing organizational implementation and adaption.

However, the results found in the review have proven to be of a mixed and somewhat inconclusive nature. This is to a high degree caused by the anecdotal nature of many of the studies reviewed. Despite this, the results of this review can be used a springboard to more focused and specific studies. Therefore, the final conclusion of this review is a call for more focused and specific research into the effects of implementing electronic whiteboards and the factors that have an impact upon these effects. Especially, research into the areas of display format, interface design, integration to other systems and user involvement seems relevant in order to increase our knowledge regarding the development and implementation of electronic whiteboards. An example of this could be to research how electronic whiteboards could be designed to work with mobile technologies e.g. smartphones and tablets in regards to the interface and display format of these technologies.

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9.2 **Paper II:** Consider the details: A study of the reading distance and revision time of electronic over dry-erase whiteboards

Declaration of co-authorship (PhD thesis)

Under Section 12 (4) of the *PhD order**, a declaration on the extent and nature of the relative contributions, signed by the collaborators and the author, must accompany the PhD thesis if the dissertation or parts of it are the result of collaboration.

Co-authors should fulfil the requirements of the Vancouver rules**

1. General information	
Name of candidate	Rasmus Rasmussen
Title of PhD thesis	Electronic Whiteboards in Emergency Medicine: Studies of implementation processes and user interface design evaluations

2. This co-author's declaration applies to the following article/manuscript No.
Rasmussen, R. and Hertzum, M., 2012. Consider the details: A study of reading distance and revision time of electronic over dry-erase whiteboard. In: Proceedings of the 12th Danish HCI Research Symposium, Sønderborg, Denmark, pp. 24-27.

The extent of the candidate's contribution to the article is assessed on the following scale:

A. has contributed to the work (0-33%)
B. has made a substantial contribution (34-66%)
C. did the majority of the work (67-100%)

3. Declaration of the individual elements	**Extent (A, B, C)**
1. Formulation in the concept phase of the basic scientific problem on the basis of theoretical questions, which require clarification, including a summary of the general questions, which it is assumed, will be answered via analyses or actual experiments/investigations.	B
2. Planning of experiments/analyses and formulation of investigative methodology in such a way that the questions asked under (1) can be expected to be answered, including choice of method and independent methodological development.	C
Involvement in the analysis or the actual experiments/investigation.	B
Presentation, interpretation and discussion of the results obtained in the form of an article or manuscript.	C

4. Co-authors' signatures			
Date	Name	Title	Signature
24/01-2013	Morten Hertzum	Associate Professor	Morten Hertzum

5. Candidate's signature
Rasmus Rasmussen

The declaration of co-authorship should be submitted with the PhD thesis to the Doctoral School.

*The Danish *Ministerial Order on the PhD Programme at the Universities (PhD order)*, no. 18 of 14 January 2008

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Consider the details: A Study of the Reading Distance and Revision Time of Electronic over Dry-Erase Whiteboards

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ABSTRACT

Electronic whiteboards are replacing dry-erase whiteboards in many contexts. In this study we compare electronic and dry-erase whiteboards in emergency departments (EDs) with respect to reading distance and revision time. We find inferior reading accuracy for the electronic whiteboard at all three levels of distance in our study. For revision time, the electronic whiteboard is slower on one subtask but there is no difference on another subtask. Participants prefer the electronic whiteboard. Given the font size of the electronic whiteboard, the inferior reading accuracy is unsurprising but the reduced possibilities for acquiring information at a glance when clinicians pass the whiteboard may adversely affect their overview. Conversely, the similar revision times for one subtask show that logon may be done quickly. We discuss how details such as font size and logon may impact the high-level benefits of electronic ED whiteboards.

Author Keywords

Electronic whiteboard, usability, efficiency, font size, logon

ACM Classification Keywords

H.5.2 [User Interfaces]: Interaction styles; Screen design.

General Terms

Design; Experimentation; Human Factors

INTRODUCTION

The benefits that motivate the introduction of many new technologies in workplaces are high-level, yet when the benefits remain unattained the reasons are often apparently mundane details. For example, systems for increasing the capacity of air-traffic control have failed because the affordances of paper flight strips were under-recognized [3], systems for asthma self-management have failed because asthmatics did not want to continually think of themselves as ill [5], and systems for facilitating collaborative planning among mutually present people have failed because the screen size was sufficient for individual use only [8].

The background for the study presented in this paper is the high-level benefits that motivate the introduction of electronic whiteboards in emergency departments (EDs) combined with our observations of some potentially influential details that appear to have entered almost unnoticed into the design of the electronic ED whiteboards in Region Zealand, one of the five healthcare regions in Denmark. Historically, dry-erase whiteboards have been used for coordinating patient care and facilitating communication among ED clinicians and have proven to be quintessential for the smooth and safe operation of EDs [7]. The motivations for replacing these whiteboards with electronic whiteboards typically include: more efficient information management, access to whiteboard information from distributed locations, integration with other electronic records, ED capacity monitoring, extraction of statistical performance data, and real-time patient tracking [4]. However, during our involvement in the implementation and evaluation of electronic ED whiteboards in Region Zealand, we observed some design details that might threaten the attainment of these high-level benefits by degrading the usability of the electronic whiteboards.

One such design detail is the font size of the textual information on the electronic whiteboards. The font size is noticeably smaller than the font size of the handwritten information on the previously used dry-erase whiteboards. Informal observation suggests that this makes the displayed information harder to read at a distance and forces the clinicians to move closer to the electronic whiteboard when retrieving information, thus slowing their work pace. Another design detail is the mechanisms for interacting with the electronic whiteboard. Compared to the ease of writing and erasing information with a marker on a dry-erase whiteboard, the process of logging on to the electronic whiteboard and then altering information using either touch screen or mouse and keyboard appears time consuming and complicated. Informal observation suggests that this process may sometimes slow down or disrupt the clinicians and possibly cause frustration. Despite these apparent drawbacks the electronic whiteboards afford the clinicians with a number of possibilities and advantages not afforded by the dry-erase whiteboard. These include standardization of the otherwise often difficult to read hand written information as well as traceability due to login requirements. We decided to compare experimentally the previously used dry-erase whiteboards with the electronic whiteboards actually used now to uncover the effect of these two design details.

WHITEBOARD DESCRIPTION

The graphical layouts of the two whiteboards are similar. Both consist of a matrix-like structure with rows and columns displaying patient related information, see Figures 1 and 2. Each row represents a patient and contains patient information such as name, age, medical problem, triage level, attending nurse, and attending physician.

The dry-erase whiteboard measured 118×146 cm. The height of each row of patient information was 8 cm. Information on this whiteboard was handwritten using dry-erase markers and augmented with colour-coded cardboard squares used for indicating triage levels. The division of the whiteboard into rows and columns was permanently marked on the whiteboard.

The electronic whiteboard is a wall-mounted 52´´ touch-sensitive monitor displaying a web application. The monitor measures 65×115 cm and has a row height of 3 cm. Information on this whiteboard is entered via the touch-screen interface or via mouse and keyboard. Clinicians log on to the electronic whiteboard by briefly holding a personal token onto a sensor. Log off is done by tapping an on-screen button.

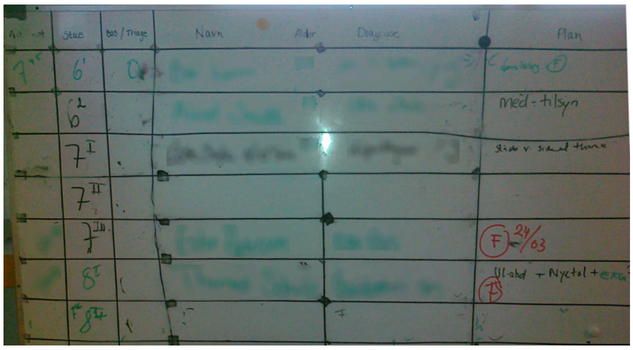

Figure 1: The dry-erase whiteboard.

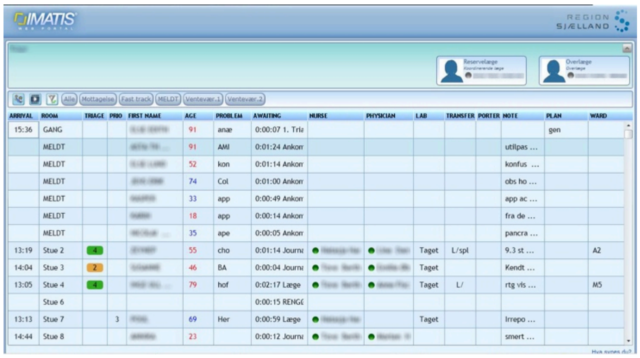

Figure 2: The electronic whiteboard.

METHOD

We conducted a within-subjects study in which participants used the electronic and dry-erase whiteboards to solve a reading task and a revision task. The healthcare region and the management of the ED approved the study prior to it being conducted.

Participants

The 18 participants (17 females, 1 male) were clinicians on duty the day the study was conducted at the ED. The participants comprised physicians, nurses, and auxiliary nurses with an average age of 49.9 years (SD = 7.7). They had an average ED seniority of 8.2 years (SD = 9.7) and rated the frequency of their use of the electronic whiteboard at an average of 20 (SD = 26.78) on a NASA TLX-like scale from 0 (often) to 100 (never). Thus, participants were experienced users of the electronic whiteboard, which had been in use at the ED for 21 months. All participants had normal or corrected-to-normal eyesight.

Whiteboards

In the study we compared the actual electronic whiteboard in use with the previously used dry-erase whiteboard. During the study the electronic whiteboard and the dry-erase whiteboard were placed in the same room away from the command room of the ED. Interaction with the electronic whiteboard was restricted to the touch-screen interface.

Tasks

The study involved two tasks: a reading task and a revision task. For the *reading task*, participants were asked to read out loud the contents of three of the whiteboard rows. The three rows were read at decreasing distances to the whiteboard, first 5, then 3.5, and finally 2 meters. The rows contained 30 to 62 characters of realistic data.

The *revision task* consisted of two subtasks: changing the triage code for a specified patient and entering transfer-to-ward information for another patient. On the electronic whiteboard, the first subtask involved logging on with the participant's personal token, changing the patient's triage code using a drop-down menu, and logging off. On the dry-erase whiteboard the same subtask consisted of changing the patient's triage code by replacing a coloured cardboard square with a square in another colour. Solving the second subtask on the electronic whiteboard involved logging on with the personal token, selecting the transfer-to-ward information from a drop-down menu, and logging off. On the dry-erase whiteboard the same subtask consisted of clearing the cell of any previous contents and writing the transfer-to-ward information with a dry-erase marker. The transfer-to-ward information was 3-4 characters in length.

We included the logon process in the use of the electronic whiteboard because actual whiteboard use at the ED consists mainly of logons to make one or two changes.

Procedure

The study was conducted at the ED in a quiet room. Participants were first welcomed, explained the procedure, and asked a few questions about their background. Then, participants solved the reading task and next the revision task. Both tasks were first solved using the electronic whiteboard, then the dry-erase whiteboard. Finally, participants rated the ease of use of each whiteboard on a scale with the anchors 'easy' (0) and 'difficult' (100) and ranked the whiteboards in order of preference. Participants were asked orally about the reasons for their preference. Each session lasted approximately 5 minutes.

Data Collection and Coding

The sessions were audio recorded to capture the data from the reading task and the reasons for participants' preference. Both authors individually coded the accuracy of the reading-task data by comparing these data to the actual whiteboard content. Accuracy was rated on a four-point scale from 1 (unable to read but may be able to discern colour codings) to 4 (fluent, error-free reading). The data from two participants were used for training, after which the authors discussed their coding. The Kappa value of the agreement between the authors' coding of the remaining participants' reading-task data was 0.80 indicating substantial agreement [2]. All disagreements between the authors were discussed and a consensus was reached.

For the revision task, the completion time for each subtask was recorded with a digital stopwatch.

RESULTS

Below we analyse the obtained data using analyses of variance (ANOVA). For the analysis of the reading task, the independent variables were the type of whiteboard and the distance whilst the accuracy rating was the dependent variable. Due to a clerical error one reading task was not audio recorded, leaving 17 participants for this analysis. For the analysis of the revision task, the independent variable was the type of whiteboard while completion time was the dependent variable. All 18 participants were included in this analysis and in the ease-of-use and preference analyses.

Distance	Electronic		Dry-erase	
	Mean	***SD***	***Mean***	***SD***
5 meters	1.71	0.92	3.65	0.49
3.5 meters	3.06	0.83	4.00	0.00
2 meters	3.76	0.44	4.00	0.00

Table 1. Accuracy (1-4) for reading task, $N = 17$

Table 1 shows the results for the reading task. There was a significant difference in accuracy between the two whiteboards, $F(1, 16) = 73.92$, $p < 0.001$, with better reading accuracy for the dry-erase whiteboard. There was also a significant difference in accuracy between the three distances, $F(2, 15) = 43.89$, $p < 0.001$. Bonferroni-adjusted pair-wise comparisons indicated that reading accuracy decreased significantly for each increase in distance. A significant interaction between whiteboard and distance on accuracy, $F(2, 15) = 30.70$, $p < 0.001$, indicated that the decreased reading accuracy at longer distances was mainly due to the electronic whiteboard.

Individual comparisons between the two whiteboards at each distance showed a significant difference in accuracy at 5, 3.5, as well as 2 meters, Fs(1, 16) = 58.86, 22.02, 4.92, respectively (all ps < 0.05). At all three distances accuracy was better with the dry-erase whiteboard. Notably, accuracy with the electronic whiteboard was not better than with the dry-erase whiteboard for any participant at any distance.

Table 2 shows the results for the revision task. For the first subtask we found a significant difference in completion time between the two whiteboards, $F(1, 17) = 12.28$, $p < 0.01$, indicating that the dry-erase whiteboard was faster than the electronic whiteboard. For the second subtask there was no difference in completion time between the two whiteboards, $F(1, 17) = 0.20$, n.s.

Subtask	Electronic		Dry-erase	
	Mean	***SD***	***Mean***	***SD***
Subtask 1	26.52	9.58	19.66	4.09
Subtask 2	25.94	11.29	24.57	4.37

Table 2. Completion time (seconds) for revision task, $N = 18$

Participants rated the ease of use of the electronic whiteboard at an average of 13.89 ($SD = 17.54$) and the dry-erase whiteboard at an average of 6.94 ($SD = 5.18$). For both whiteboards the rating is closer to the "easy" (0) than the "difficult" (100) end of the scale. There was no difference in ease-of-use rating between the two whiteboards, $F(1, 17) = 2.36$, n.s.

In terms of preference, 13 participants preferred the electronic whiteboard, 2 preferred the dry-erase whiteboard, and 3 had no preference. A Friedman test of the preference data showed a significant preference in favour of the electronic whiteboard as a whole, $\chi^2(1, N{=}18) = 8.07$, $p < 0.01$.

The participants gave several reasons for preferring the electronic whiteboard. Generally, the participants preferred the electronic whiteboard as a whole because it was easy to use, because it was a smarter system than the dry-erase whiteboard, because it provided more information than the dry-erase whiteboard, and because the text displayed is independent of personal handwriting styles and thus always legible. The most frequent reason stated in favour of the dry-erase whiteboard was that it was very reliable because it had no down time.

DISCUSSION

Given the design of the electronic whiteboard it is unsurprising that the dry-erase whiteboard can be read accurately at greater distance and revised at least as quickly. What is surprising is that the importance of being able to read and revise the whiteboard information accurately and rapidly seems to have been down prioritized compared to other design considerations e.g. showing more information.

The ED clinicians often glance at the electronic whiteboard in passing, as opposed to stand in front of it scrutinizing its contents. Similarly, the ability to gain an overview by simply glancing at the display is an important feature of other systems [6]. The possibility of retrieving information "at a glance" seems particularly important and useful in situations of fast pace and high workload. While such situations are common in EDs, this study shows that the electronic whiteboard has reduced the clinicians' ability to read the whiteboard information accurately, especially at longer distances. This may impair the clinicians' ability to quickly gain an overview of the ED status, in turn slowing down their work pace. An advantage of the electronic whiteboards is, however, that this system provides more and better information, which to some extent seems to negate the disadvantages of not being able to retrieve information "at a glance".

The time required to revise the electronic whiteboard is longer for one subtask and the same for the other subtask, compared to the dry-erase whiteboard. While the slower performance on the triage subtask is important because triage codes are set and changed 100+ times a day, the similar performance on the transfer-to-ward subtask is the more surprising because the use of the electronic whiteboard involves logon. A candidate explanation for the similar performance on the transfer-to-ward subtask is that the physical token carried by the clinicians provides for an efficient logon procedure. The logon procedure is particularly important in hospital environments because work in these environments is nomadic, frequently interrupted, and characterized by brief periods of use [1]. Thus, clinicians perform the logon procedure many times a day. Bardram [1] identifies logon as one of the reasons why electronic systems often cause more frustration amongst clinicians than their manual counterparts. The participants' preference for the electronic whiteboard and the absence of a difference in their ease-of-use ratings suggest that the logon procedure is considered quick and simple. The difference in revision time for the triage subtask, which also involved logon, shows however that the interaction mechanisms, including logon, of electronic whiteboards still need to be improved to compare with making simple changes on dry-erase whiteboards. A further challenge in devising these interaction mechanisms is that during real ED work clinicians often manipulate the whiteboard while having a phone in one hand and some papers in the other.

In order to avoid that important details go unnoticed in design processes and thus end up hampering system use, we recommend that systems be evaluated in the field before their design is finalized. Such pilot implementation under realistic conditions appear more likely to lead to the identification of mundane details, such as the importance of accurate reading at a glance, than more fieldwork prior to the design phase or more reflection during the design phase.

CONCLUSION

This study shows that design details that may seem mundane and trivial can impact the usability of electronic whiteboards. The smaller font size of the electronic whiteboard reduces participants' ability to read whiteboard content accurately; this may reduce ED clinicians' ability to retrieve information at a glance and slow them down. The participants perform some whiteboard revisions slower with the electronic whiteboard and others equally fast with the two whiteboards. The similar performance on some revision tasks shows that logon does not necessarily consume extra time. The logon procedure seems to be efficient and fit well to ED work. In sum, apparently mundane details may have a substantial impact on the usability of a system. To tease out such details before a system is taken into operational use we recommend evaluation in the field.

ACKNOWLEDGEMENTS

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9.3 **Paper III:** Digital video analysis of health professionals' interactions with an electronic whiteboard: A longitudinal, naturalistic study of changes to user interactions

Declaration of co-authorship (PhD thesis)

Under Section 12 (4) of the *PhD order**, a declaration on the extent and nature of the relative contributions, signed by the collaborators and the author, must accompany the PhD thesis if the dissertation or parts of it are the result of collaboration.

Co-authors should fulfil the requirements of the Vancouver rules**

1. General information	
Name of candidate	Rasmus Rasmussen
Title of PhD thesis	Electronic Whiteboards in Emergency Medicine: Studies of implementation processes and user interface design evaluations

2. This co-author's declaration applies to the following article/manuscript No.
Rasmussen, R. and Kushniruk, A., 2012. Digital video analysis of health professionals' interactions with an electronic whiteboard: A longitudinal, naturalistic study of changes to user interactions. Submitted for publication to Journal of Biomedical Informatics.

The extent of the candidate's contribution to the article is assessed on the following scale:

A. has contributed to the work (0-33%)
B. has made a substantial contribution (34-66%)
C. did the majority of the work (67-100%)

3. Declaration of the individual elements	**Extent (A, B, C)**
1. Formulation in the concept phase of the basic scientific problem on the basis of theoretical questions, which require clarification, including a summary of the general questions, which it is assumed, will be answered via analyses or actual experiments/investigations.	C
2. Planning of experiments/analyses and formulation of investigative methodology in such a way that the questions asked under (1) can be expected to be answered, including choice of method and independent methodological development.	C
Involvement in the analysis or the actual experiments/investigation.	C
Presentation, interpretation and discussion of the results obtained in the form of an article or manuscript.	C

4. Co-authors' signatures			
Date	Name	Title	Signature
Jan. 14, 2013	Andre Kushniruk	Professor	Andre Kushniruk

5. Candidate's signature
Rasmus Rasmussen

The declaration of co-authorship should be submitted with the PhD thesis to the Doctoral School.

*The Danish *Ministerial Order on the PhD Programme at the Universities (PhD order),* no. 18 of 14 January 2008

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Digital video analysis of health professionals' interactions with an Electronic Whiteboard: A longitudinal, naturalistic study of changes to user interactions

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Abstract

As hospital departments continue to introduce electronic whiteboards in real clinical settings a range of human factor issues have emerged and it has become clear that there is a need for improved methods for designing and testing these systems. In this paper we describe the results of a longitudinal and naturalistic digital video based usability study of an electronic whiteboard system and discuss the results as well as the methodology we developed. We found that the electronic whiteboard system contains system related usability issues that did not change over time as the clinicians collectively gained more experience with the system. Furthermore, we also found user related issues that seemed to change as the users gained more experience and we discuss the underlying reasons for these changes. We also found that the method used in the study has certain advantages over traditional usability evaluation methods but acknowledge that there are challenges and drawbacks to using the method that should be considered before utilizing a similar approach. In conclusion we summarize our findings and call for an increased focus on longitudinal and naturalistic evaluations of health information systems and encourage others to apply and refine the method utilized in this study.

Keywords: Usability evaluation, longitudinal, naturalistic, video-based, methodology, electronic whiteboards

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1. Introduction

As hospitals worldwide move to increased automation, a wide variety of information systems are becoming deployed in settings such as emergency departments. One such application, the electronic whiteboard (EW) is being increasingly deployed to increase patient safety. In addition, EW functionality is beginning to be integrated with other hospital systems such as patient tracking and coordination systems. Previous research has shown that replacing dry-erase whiteboards with EWs can lead to improved and timelier access to patient information [1], [2][3]. However, as we move to greater use of such health information technologies in real clinical settings, a wide range of human factor issues have emerged and it has become clear that there is a need for improved methods for designing and testing EWs that are to be integrated into complex work practices in settings such as the emergency department (ED) [4], [5]. For example, Wong et al. [6] found the need for a number of enhancements to an EW after it was deployed as well as the need to conduct workflow review meetings to ensure adoption. A comparative study of manual whiteboards and EW systems [7] used interviews and observations of users of EWs to identify issues related to need for flexibility, need for local customization by clinicians and the incorporation of new and emerging needs into EWs. In another line of research Riley et al. [8] have demonstrated how implementation of EWs can lead to inadvertent changes in power, work activities and professional control in clinical practice.

In this paper we describe our work in conducting naturalistic video-based analyses of user interactions with a new EW system that has been deployed in two emergency departments at Danish hospitals. The goals of the study are to identify specific usability problems, potential inefficiencies and workflow issues associated with use of an EW deployed in the emergency departments. We are also interested in understanding if there would be differences in human factor and workflow issues in departments that have adapted to the same EW some time after deployment as compared to a more recent deployment. The approach to evaluating use of EWs we have developed was designed to augment and complement an initial participatory design approach described by Rasmussen et al. [9], [10].

Methods which have been previously used to evaluate the use of EWs have included methods ranging from surveys and interviews given to EW users [8] to observation of users [11] to collecting and analyzing static digital photographs taken of EW screens [7]. Limitations of these methods include difficulty in collecting data about how the system responds over longer periods of time to a wide range of user interactions in real settings, which could only be obtained by collecting detailed live and continuous naturalistic recordings of user interactions.

In this article we describe our work in employing a method whereby continuous screen recordings of user interactions with an EW being studied are analyzed using a new approach to digital video analysis of continuous screen recordings. By continuously recording live user interactions over time with applications such as EWs, a large and rich data set can be collected that can be used to assess usability problems and help describe adoption issues when such applications are deployed in real clinical and emergency settings over time. Our previous work has shown that although laboratory testing of healthcare applications applying usability methods is needed, it is not sufficient for ensuring the safety and effectiveness of healthcare applications deployed in complex settings [12]. In the area of video analysis of user interactions, previous work has been published about video and screen recording and resultant analysis of healthcare professional interactions in the context of usability testing [13] and the extension of usability testing to more realistic simulations, termed "clinical simulations" [12]. However, there has been less work describing effective approaches to the naturalistic analysis of video recorded user interactions' with systems and patients once a system has been deployed in a real clinical setting. To address this issue, in this paper we describe the approach we have developed and applied to collecting and analyzing large data sets of continuous live screen recordings of user interactions with an EW system over time.

2. Methods

We conducted a qualitative longitudinal and naturalistic study of the ED clinicians' use of the EW system following the procedure described later in this section. The healthcare region and ED management approved the study prior to it being conducted. Since the recordings would contain personal data regarding patients at the ED the study also had to be registered and approved by the Danish Data Protection Agency and follow the guidelines outlined in their directive. Clinicians on duty during recording sessions were briefed on the study during morning meetings and throughout the days if there were any questions or concerns.

2.1 The electronic whiteboard

The EW system analyzed in this study is a web-based application installed on a central server. The system is accessible from all devices connected to the same network as the server, which affords flexible and distributed access to the system. Clinicians can access the EW system from multiple access points throughout the department e.g. workstations, laptops and mobile devices. The main access points and most prominent artifacts of the system are the 52-inch touch sensitive wide-screen displays located in central command rooms throughout the departments. Clinicians from all professions use these displays for updating, retrieving and discussing patient information. Other important access points to the EW system include the workstations used by the secretaries, the triage nurses and coordinating nurses. From these access points the secretaries, the coordinating nurses and triage nurses enter new patients as they are reported to the department and distribute them between the different areas of the departments as they arrive. During a normal day shift these access points have only one or two primary users while the wide-screen displays may have multiple users accessing the system. Access to the EW through the wide-screen access points is protected by a login mechanism where users identify themselves by scanning a personal chip, which unlocks the system. Login at the personal access points e.g. triage nurses workstation and other personal work stations is handled by the work station login mechanism and users do not need to specifically login to the EW system at these access points.

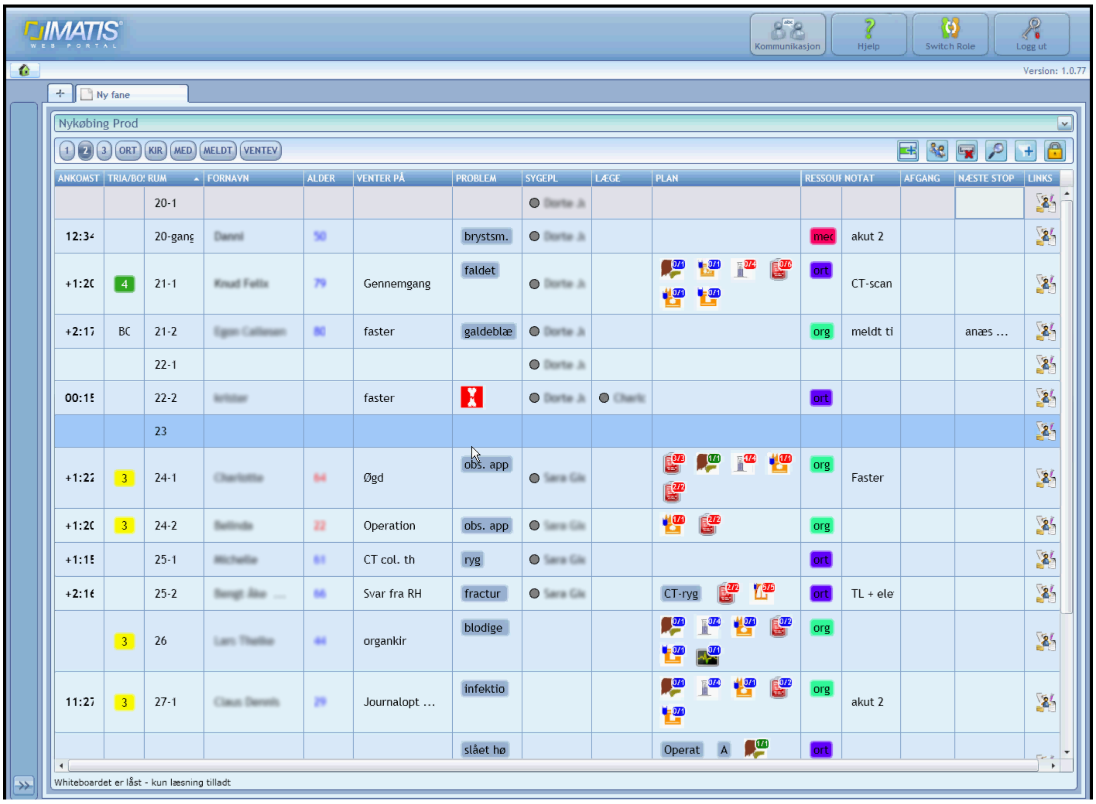

Figure 1: A screenshot of the EW as it is configured for the wide screen displays at ED1

The EW system displays information relevant for coordinating the clinicians' work of attending patients and keeping track of each patient's treatment process. This includes information regarding the patients' medical problems, triage levels, lab results, plans for further treatment and what department the patients will be transferred to in case they need hospitalization. The EW system has the possibility of automatically retrieving and displaying information from other clinical IT systems e.g. laboratory, radiology and patient monitoring systems. This option was implemented in one of the two departments where this study was performed. Besides the above information the EW system also displays the patients' first names, their age and their location in the department as well as the name of the nurse and physician currently responsible for attending to the patient. Figure 1 shows a screenshot of the EW system as it is configured at one of the two ED's. The EW system can be configured individually to match unique work practices at different departments. However, the main functionality and purpose of the system is the same at both departments involved in this study.

2.2 Setting

The two departments (ED1 & ED2) where this study was carried out are both relatively newly established emergency departments at two larger hospitals in the Danish healthcare region of Zealand. Both departments participated in a larger project of developing, implementing and evaluating the EWs during the time of the study. The two departments are similar to each other in terms of their organizational structure and the tasks that they perform in the hospital. Both departments have nurses and a number of chief physicians employed directly and have resident physicians attached on an on-call basis. On average there are 20 nurses, 6 physicians and 5 medical secretaries on duty during a normal day shift at ED1 and for ED2 the numbers are 16, 9 and 5 respectively.

In regards to this study the two departments differ in terms of how much experience each department as a whole has had with the EW. Data from the first emergency department (ED1) was collected approximately 1.5 years after the EW had been installed in that department (which we will henceforth refer to as $ED1_{LATE}$). Data was also collected at two times from a second emergency department (ED2) which had installed the same EW application more recently: (a) approximately 1.5 months after the EW was installed (which we henceforth refer to as $ED2_{EARLY}$) and (b) approximately 5.5 months after the EW was installed (which we henceforth refer to as $ED2_{MID}$).

2.3 Materials

The materials used for data collection in this study were selected for their inexpensiveness in order to assess the usefulness of a low cost approach to collecting live user data. The main components included three 4Gb flash drives with the free version of the screen-recorder software HyperCam 2 ® installed as well as three 2Tb external hard drives and three 16Gb flash drives for storage of resultant digital screen recordings. To support the analysis of the digital video files the free f5 ® coding tool was used (which facilitated timestamping and annotating of the digital video during analysis)

2.4 Procedure

User interactions with the EWs were captured using the HyperCam 2 software installed on flash drives as described above. The resulting digital movie files were stored on either an external hard drive or one of three 16 Gb flash drives. Using this setup there was no need for installing any software on the machines where the recordings were performed and no need to take up local storage space during the recordings.

User interactions with the EW were captured over a period of five days between 10 AM and 4 PM each day. This period was specifically chosen because experience showed that this was often the busiest time of day at the two EDs and therefore should produce the highest number of interactions with the EW system. The recordings were performed at three different access points in the two EDs. At ED1 the coordinating and triage nurses have their own workstations in separate locations in the department. Because these access points to the system were deemed to be regularly and frequently used recordings were performed here each day in the five-day session. Interactions with the system through the wide-screen displays rotated between two of the command rooms in the department. At ED2 the same person holds the role of coordinating and triage nurse. At this department the coordinating/triage nurse shares two workstations with a secretary so recordings rotated between these two machines. Recordings of interactions with the system through the wide-screen displays rotated between the different command rooms of the department.

To capture how user interactions with the system changed over time recordings were performed initially at $ED1_{LATE}$, then at $ED2_{EARLY}$ and 5 months later at $ED2_{MID}$ following the procedure described above.

2.5 Data analysis

Initially, each digital movie file was viewed and logged by the first-author using a predefined coding scheme developed by the authors – see Figure 2.

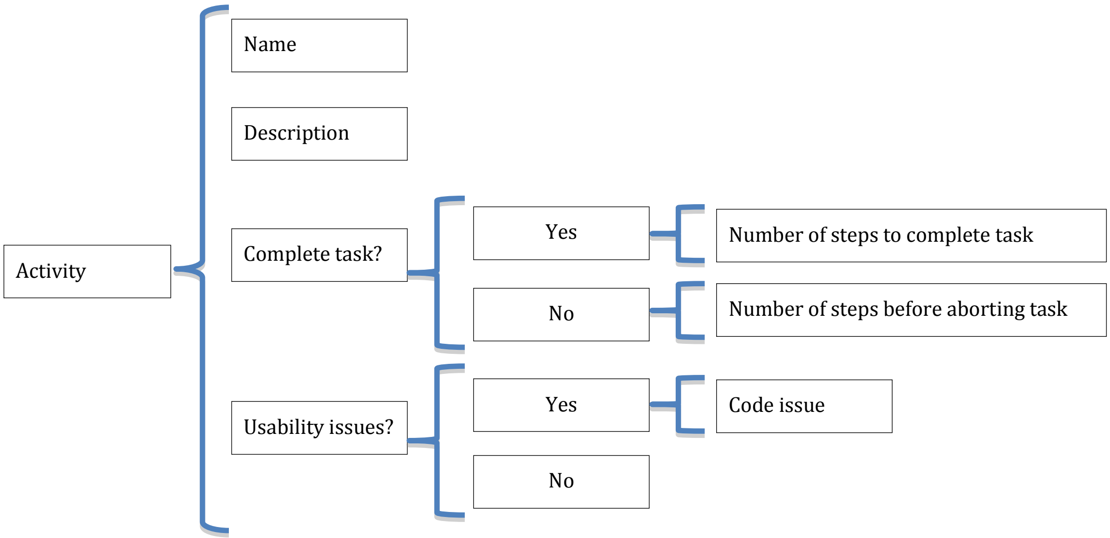

Figure 2: The coding scheme used for logging on-screen activities

Using this scheme on-screen activity was recorded and entered via a word-processor as entries in separate log files. In this context a log entry is thusly defined as any on-screen activity captured by the screen-recording software. This includes user initiated activity as well as system initiated activity e.g. error messages presented to the user. As a minimum each entry in the log files contains an auto-generated timestamp (corresponding to system-user interactions observed on the digital video of the EW screens), an activity indicator, a name for the activity and a description of the activity. In instances of user initiated activity the entries also contain an indicator of whether or not the task was completed and the number of steps used in completing the task or before aborting the task. When usability issues were discovered we marked the entries with an indicator and coded the issues using the coding categories found in Table 1. We also provided a description of the issue including whether or not the user solves the issue.

Following the logging process each log file was perused and any activities of interest were coded for further analysis. In coding the log files we also looked for relationships between the different entries e.g. the different entries that make up work patterns. We then summarized the total number of entries and average number of entries for each recording session at each access point. For each usability issue, we tabulated the total number of times the issue occurred in total and calculated the number of times each issue occurred per hour. To control for variations in the total number activities logged during each recording session we also calculated the percent-wise distribution of each issue relative to the total number of activities recorded at each type of access point for $ED2_{EARLY}$, $ED2_{MID}$, and $ED1_{LATE}$ respectively.

Table 1: The categories used for coding usability issues

Coding category	Definition
System bug	Issues caused by errors in the EW system
Efficiency problem	Issues related to the efficiency of using the EW system
Error message	Issues causing the EW system to present error messages
Work patterns	Issues regarding work patterns related to solving specific tasks with the EW system

The initial logging of the digital video files was performed solely by the first-author due to restrictions imposed by the Danish Data Protection Agency's directive. After having logged the digital video files both authors were involved in the coding of the log files and the following analysis work. All codings were discussed amongst the authors to mitigate biases in the analysis (and any differences in coding were resolved through discussion).

3. Results

The result of the recordings was 166.5 hours of video data (i.e. continuous digital video recordings of all recorded user interactions with the EW) divided between 45 digital video files each lasting on average 3 hours and 41 minutes. No audio was recorded due to the lengthy continuous nature of the recordings and the clinicians' concern for disclosing sensitive information regarding patients and colleagues. As such each video file contained only the continuous screen recordings of the clinicians' interactions with the EW system.

Using the logging scheme described previously a log corresponding to each digital video file was created in a text file for further analysis. A total of 2863 entries were logged producing an average of 64 entries per log file. Table 2 shows basic data for the recordings including total number of entries and average number of entries logged at each type of access point at the three EDs. Due to the naturalistic approach used in this study the results are naturally influenced by the work practices and EW usage patterns that exist within the EDs where the recordings were preformed e.g. fluctuating periods of low or high usage. Also, due to technical difficulties a few of the recordings were ended prematurely resulting in shorter periods of screen recording than had been planned. The resulting log files (e.g. from the three recorded sessions) are therefore not directly comparable in terms of number of entries – see Table 2. To counter for differences in the number of total entries per recorded sessions, rather than directly comparing frequencies of usability issues from the different session, we calculate the percentage-wise distribution of the identified usability issues relative to the total number of log-entries per session whenever comparing distribution of usability issues across the three recording sessions.

Table 2: Total and average number of entries across access points and recording sessions

Location	Access point	Total number of entries	Total recording time per access point (hours)	Average number of entries per hour
ED2$_{EARLY}$	Wide screen	417	20.1	20.7
	Triage/coordinating nurse	290	26.8	10.8
ED2$_{MID}$	Wide screen	720	32.2	22.4
	Triage/coordinating nurse	721	21.5	33.6
ED1$_{LATE}$	Wide screen	400	21.9	18.3
	Triage/Coordinating nurse	315	43.9	7.2

#01:36:01-3# --> #01:36:19-3#
[Activity] [Name: Updating patient information]
[Description: Upon noticing that the system did not update the "Waiting for" field (see previous entry) the user clicks again on the field and brings up the associated dialog box. Once again the user wants to enter free text and clicks on the free text option. However, upon entering the first character the cursor jumps to the search field and the user continues writing in this field. Upon noticing the error the user clicks in the free text field and this time enters the information correctly]
[Complete task] [Number of steps: 5]
[Usability problem] [System bug: Cursor jumps from free text field to search field after the user enters the first character]

Figure 3: A snippet from one log file

3.1 Log entries

Figure 3 shows a snippet containing an entry from one of the log files. The entry reveals the timestamp for the activity recorded and then annotates the activity using the "Name" field of the coding shown in Figure 3. In this case the activity has been identified as "Updating patient information" and the description details the interactions included in this activity.

After this the entry indicates that the activity was completed in five steps and that there was a usability issue during the activity. An identifier and a description of the issue detected are included. Table 3 shows similar examples of entries for each of the four categories of usability issues. In coding the log files we found a number of specific issues related to each of the different categories in the coding scheme. Table 4 shows these issues and the total number of times each specific issue occurred in the log files. In some cases we grouped entries under the same issue. This was done in cases where issues were found to be of the same nature e.g. different types of system errors.

3.2 Work patterns and related entries

In analyzing the work patterns observed we were interested in uncovering how these patterns changed over time as the ED staff members collectively gained more experience with the EW system over time. To that end we looked for examples of work patterns that appeared to be carried out in both efficient and inefficient ways.

As seen in Table 3 the work patterns coded are defined by a number of entries directly related to each other through the task which they form part of. An example of a work pattern is the task of updating and transferring patient information from one view of the EW to another. This task consists of a number of steps where the user updates patient information e.g. time of arrival, triage level, medical problem etc. After updating this information the user updates the patient's location to indicate that the patient is being moved to another part of the department e.g. from arrival to a patient room in the department.

Table 3: Examples of user issues found and their related categories

Coding category	Log file example
System bug	**[Activity] [Name:** Updating patient information] **[Description:** User opens "Next stop" field's dialog box and enters the next stop for the patient in the free text field. However, upon clicking "Ok" and closing the dialog box the patient information is completely deleted**] [Not complete task] [Number of steps:** 4**] [Usability problem] [System bug:** When entering free text information in the "Next stop" dialog box the system deletes all information for the current patient**]**
Efficiency problem	**[Activity] [Name:** Updating patient information**] [Description:** User updates "Next stop" field with information regarding where the patient is going to be sent next**] [Complete task] [Number of steps:** 5**] [Usability problem] [Efficiency problem:** The user enters the information in both the free text field and the search field when it would only have been necessary to enter the information in the free text field. Adds another step to the process. Possibly caused by confusion regarding which field does what**]**
Error message	**[Activity] [Name:** Updating patient information**] [Description:** User opens the "Waiting for" field's dialog box and selects the wanted option to indicate what the patient is currently waiting for**] [Not complete task] [Number of steps:** 3**] [Usability problem] [Error message:** The system displays an error message saying that there is newer information available and that the current update will be cancelled - see remark.**]** Remark: Because the user updated the "Location" before updating the "Waiting for" field the patient has effectively been removed from this view of the electronic whiteboard when the user completes the current update.
Work patterns	**[Activity] [Name:** Updating patient information**] [Description:** User opens the "Waiting for" field's dialog box and selects the wanted option to indicate what the patient is currently waiting for**] [Complete task] [Number of steps:** 3**]** **[Activity] [Name:** Updating patient information**] [Description:** User opens the "Triage" field's dialog box and selects the appropriate triage level for the patient**] [Complete task] [Number of steps:** 2**]** **[Activity] [Name:** Updating patient information**] [Description:** User opens the "BOS" field's dialog box, enters the patients BOS and clicks the "Ok" button to save the entry**] [Complete task] [Number of steps:** 2**]** **[Activity] [Name:** Updating patient information/Removing patient from whiteboard**] [Description:** User opens the "Location" field's dialog box, selects the "Team 1" tab, selects a option under this tab and clicks "Ok" to confirm the selection. This removes the patient from the current view of the electronic whiteboard**] [Complete task] [Number of steps:** 4**]**

This transfers the patient and related information from one view of the whiteboard to another. While coding the log files we found that the users in some cases followed efficient work patterns in terms of the sequence of steps to carry out the task. However, in other situations we observed that some subjects would follow what appeared to be less efficient work patterns. In the example of updating and transferring patient information the less efficient work pattern involved updating the location information before having updated the other information. This causes the system to move the patient and forces the user to switch to another view of the EW and restart the information update.

Another example of efficient and inefficient work patterns is when the EW users remember to log in to the system versus when they forget to log in before initiating any activity (i.e. where the system would appear to let the user into the system but would not allow them to complete a task until they went back and logged in).

Table 4: The issues related to the different coding categories. The numbers for the work patterns indicate how many instances of the efficient pattern occurred compared to the less efficient pattern

Coding category	Identifier	Description	Total number of instances
System bugs	Other system bugs	Includes disappearing patients, multiple patients, clinicians not appearing in list, information not being updated, system crashes and system opens wrong field.	19
	Floating pop-ups	Pop-ups related to one field on the EW display "wanders" around on the display	15
	Jumping cursor	When writing in one text field within the EW system the cursor jumps spontaneously from one text field to another	13
	System allows update of moved patients	Even though a patient has been transferred to another view the user can sometimes start an update of that patient which results in either the wrong patient being updated or an error message	8
Efficiency problem	Complicated and long pathways	Some pathways to solving different tasks in the EW system require many steps to complete	63
	Other efficiency problems	Issues that occur less than five times in total or at only one location. Includes issues regarding user mistakes, unsuccessful user actions, menu items not available, not enough information provided	48
	Incorrect use of interface elements	The clinicians use the interface elements in an incorrect manner e.g. trying to search with free text field or entering identical information in multiple fields	19
	Menu item confusion	Indications that the users have trouble finding menu items when using the EW	11
Error message	Newer information available	Updating information on the EW sometimes causes the system to display a message saying that newer information is available and that the current update will be cancelled	26
	Browser errors	Generic browser errors caused by the EW application	7
	Other error messages	Issues that occur less than 5 times in total or at only one location. Includes messages regarding authentication errors, duplicate rows and unavailable resources	5
Work patterns	Login to system before interaction	Access to the EW through the wide screens is only possible if the clinicians login	179/184
	Updating and transferring patients	When updating patient information and afterwards transferring the patient to another EW view the transfer should not be done until all other information has been updated	62/45

Also, we found that a number of the individual issues are related. An example of this is the relationship between the work pattern of transferring patients, the error message regarding newer information and a system bug that allows the user to update patients that have been moved from the selected view of the EW.

When a user follows the less efficient work pattern of updating and transferring patient information a system bug will sometimes allow the user to continue updating patient information on the same patient even though this patient has been removed. When the user completes the update the system displays an error message saying that there is newer information available and that the current update has been cancelled. These types of errors were detected in the analysis of the digital video files.

3.3 Comparing issue distribution

In order to determine how time since implementation affects the different usability issues described above we compared the percentage-wise distribution of the different issues relative to the total number of log-entries per session – see Table 5. As Table 5 shows the usability issues identified found generally do not occur often during use of the EW system (which as will be discussed points to the need to do longer continuous recording of interactions to identify problems that might be important to identify but are infrequent). Also, a number of the issues occur at only one type of access point. This is either due to the nature of the access points e.g. wide-screens requiring log-in or the tasks performed at the access point e.g. updating and transferring patients reveals the bug where users can update a removed patient.

Table 5 shows that the system-related issues e.g. system bugs, error messages and system-related efficiency issues, were not affected by increasing departmental experience with the system. The results show that these issues occur unsystematically and there does not appear to be any pattern in how often they occur across the three recordings sessions. However, a number of the user-related issues do seem to be affected by increasing departmental experience with the EW system. This is especially true for the work patterns identified in the analysis. As Table 5 shows it appears that the patterns followed by the users of the EW system do change over time.

In order to uncover how often the efficient patterns were followed compared to the inefficient patterns we calculated the percent-wise distribution for both the efficient pattern and inefficient patterns relative to the total number of work pattern instances recorded across the different types of access points – see Table 6. As Table 6 shows the users of the EW system at $ED2_{EARLY}$ followed the efficient login work pattern in 65 % percent of all instances where a user logs in and uses the system. For $ED2_{MID}$ this number dropped to 60.92 % and at $ED1_{LATE}$ the same number is 9.20 %. This indicates that the experienced users at ED1 have a tendency to be less efficient than the less experienced users at ED2 with regards to this work pattern. Also, this indicates that the users at ED2 have a tendency to forget to login more often as they gain more experience with the EW.

For the update and transfer work pattern the situation is reversed. As Table 6 shows, the users at $ED2_{EARLY}$ would follow the efficient work pattern in 35 % of all instances while at $ED2_{MID}$ the users would followed the efficient work pattern in 47.46 % of all instances of this work pattern. And at $ED1_{LATE}$ the users would follow the efficient work pattern in 96.43 % of all instances of this work pattern. These results indicate that the experienced users at ED1 have a tendency to be more efficient than the less experienced users at ED2 with regards to this work pattern.

Table 5: The percent-wise distribution of the found issues relative to the total number of log-entries per session

Coding category	Issue identifier	Access point type					
		Wide screen			Work stations		
		$ED2_{EARLY}$	$ED2_{MID}$	$ED1_{LATE}$	$ED2_{EARLY}$	$ED2_{MID}$	$ED1_{LATE}$
System bugs	Other system bugs	0.24%	0.56%	0.25%	0.69%	0.42%	2.54%
	Floating pop-ups	0.00%	0.28%	0.25%	0.00%	0.28%	3.17%
	Jumping cursor	1.20%	0.28%	0.25%	0.69%	0.00%	0.95%
	System allows update of moved patients	0.00%	0.00%	0.00%	1.03%	0.69%	0.00%
Efficiency problem	Complicated and long pathways	0.00%	0.42%	0.50%	5.52%	4.99%	1.90%
	Other efficiency problems	0.72%	3.61%	3.75%	0.34%	0.14%	0.63%
	Incorrect use of interface elements	1.20%	0.00%	0.50%	0.00%	0.00%	3.81%
	Menu item confusion	0.24%	0.28%	1.50%	0.00%	0.00%	0.63%
Error message	Newer information available	0.00%	1.25%	0.00%	1.03%	1.11%	1.90%
	Browser errors	0.48%	0.14%	0.00%	0.00%	0.00%	1.27%
	Other error messages	0.24%	0.14%	0.00%	1.03%	0.00%	0.00%
Work patterns	Login to system before interaction (efficient)	15.59%	14.72%	2.00%	0.00%	0.00%	0.00%
	Login to system before interaction (inefficient)	8.39%	9.72%	19.75%	0.00%	0.00%	0.00%
	Updating and transferring patients (efficient)	0.48%	0.42%	3.25%	1.72%	3.47%	4.44%
	Updating and transferring patients (inefficient)	0.24%	0.00%	0.00%	4.14%	4.30%	0.32%

However, the results also show that the users at ED2 seem to become more efficient with increased experience with the EW system. In the following we will discuss these findings and related them to previous and similar work.

Table 6: The percent-wise distribution of efficient and inefficient work patterns relative to the total number of work patterns instances

Work pattern	$ED2_{EARLY}$	$ED2_{MID}$	$ED1_{LATE}$
Login to system before interaction (efficient)	65,00%	60,92%	9,20%
Login to system before interaction (inefficient)	35,00%	39,08%	90,80%
Updating and transferring patients (efficient)	35,00%	47,46%	96,43%
Updating and transferring patients (inefficient)	65,00%	52,54%	3,57%

4. Discussion

Through our analysis of user interactions with the EW system we found a range of different categories of usability issues and within each of these categories we found a number of specific issues. A number of the issues found were related to the design and technical implementation of the EW system e.g. system bugs, error message and system-related efficiency issues. Other issues were related to the users of the EW system e.g. inefficient work patterns and user-related efficiency issues. Although the usability issues did not occur frequently it is interesting to note that the same issues occurred at both EDs and at all three intervals since implementation i.e. $ED2_{EARLY}$, $ED2_{MID}$ and $ED1_{LATE}$.As Table 5 indicates the system-related usability issues found do not appear to change over time as the users of the EW system gain more experience with the system. Kjeldskov et al. [14] found the same pattern in their longitudinal usability study of an EPR system. In this study the authors found that as the users of the EPR system gain more experience with the system the usability issues they face are similar to problems they uncovered as novices both in terms of type and severity.

However, from Table 6 we find that the work patterns uncovered in the analysis do indeed seem to be affected by the users gaining more experience with the EW system. In the following we will discuss these changes to work patterns and relate our findings to similar studies. Also, we will discuss the methodology used in this study including the limitations and challenges associated with using this method.

4.1 Work pattern changes

In our results we found work patterns that seem to be affected by how much time has passed since the system was implemented at the ED. One example of such a work pattern is related to the task of updating and transferring patient information from one view of the EW to another. In our results we found that the clinicians at $ED2_{EARLY}$ would follow an efficient work pattern in only 35 % of the time when completing this task. At $ED2_{MID}$ this number had increased to 47.46 % and for $ED1_{LATE}$ the same number was 96.43 %. This indicates that there is a tendency in our results for the clinicians to become more efficient with increasing departmental experience with the EW system.

In their study Kjeldskov et al. [14] report a similar tendency. Even though this study finds that users do not become significantly more efficient in completing tasks as they go from novices to experts the authors note that experts were faster in simple data entry tasks e.g. typing in patient values [14]. These tasks are similar to the tasks that compose the work pattern of updating and transferring patient data in the EW system. Vaughan et al. [15] report on a similar trend in their longitudinal study of readers of a web-based newspaper. Here, the authors find that with time the newspaper readers become increasingly efficient as they gain more experience with the different versions of the newspaper involved in the study. This is positive because it indicates that despite having issues in the initial stages of usage the users of the EW system have the ability to overcome these issues and learn to use the system in an efficient manner.

Interestingly, our results also show that in some cases the users of the EW system became less efficient with increasing departmental experience. An example of this is the work pattern of logging in to the EW system before starting any update of the information shown. In this instance we found that the clinicians at $ED2_{EARLY}$ and $ED2_{MID}$ were more efficient than the clinicians at $ED1_{LATE}$ despite the department having had the EW system implemented more recently. As [16] finds it is crucial that the login mechanism for any healthcare information system is well designed to fit into the *"highly nomadic, dynamic, interrupted, and cooperative work in hospitals"* [16]. The login mechanism for the EW system resembles the silent login mechanism that [16] presents as one possible login mechanism for systems similar to the EW making the process of logging in to the system relatively easy. Also, a previous study of the EW system has shown that the chip reader login mechanism does not have a negative impact on the systems usability [17]. Therefore, it is interesting to note that our results show a tendency for the clinicians to forget to login more frequently the more experience they gain with the EW system. A possible explanation of this trend could lie in the novelty value of the system at the two EDs and how the procedure of logging to the system fits into the clinicians' perception of their work tasks with the EW.

As witnessed by the high number of login interactions, EW usage is characterized by frequent and rapid interactions see – see Table 4. This is distinct for the nomadic work practices commonly found in hospital departments [16]. In a situation where nomadic work practices influence and characterize the way the clinician's use the EW the concept of logging on might not fit well with their everyday work with the EW system. In other words the idea of first logging into the system might not be present in the clinician's minds when using the system to carry out their tasks and this would not change as the clinician's gain more experience with the system.

Furthermore, as the clinicians move further away from the point in time when the system was implemented the novelty of the system and thereby the explicit recollection of how to use the system might wear off. As Ahmed et al. [18] report in an analysis of users' ability to learn and retain the functionalities of a web-based information retrieval interface, novice users were found to have the ability to learn how to use an interface relatively easily through hands-on training. However, it was also found that the test subjects were unable to retain what they had learnt in a second test session four weeks later and performed worse than during the first session [18]. In their discussion Ahmed et al. [18] argue that with time the users forget some of the functionalities of the interface. Following this line of thought we argue that because the EW system and associated training is fresher in the minds of the novice users at $ED2_{EARLY}$ and $ED2_{MID}$ they tend to follow the efficient login work pattern more often than the experienced users of $ED1_{LATE}$, because they are still aware of the system and better recall their initial training. Also, our results show that problems with login mechanisms in healthcare information systems are a recurring issue that still needs to be researched and refined in order to not be a hindrance to the efficient use of systems such as the EW studied here.

4.2 Discussion of methodology

The aim of the methodology applied in this study is very similar to those of other usability evaluation methods i.e. uncovering usability issues in the design of a given system. However, the method applied here differs from many of the more traditional usability evaluation methods in its naturalistic and longitudinal approach. Where methods such as usability testing involving think-aloud protocol analysis [19], [13] or clinical simulations [12] are capable of uncovering usability issues in a relatively short time frame, the method employed here has the capability of uncovering issues that occur on a longer time scale in a naturalistic setting e.g. infrequently occurring (but potentially important or serious) issues that only occur under specific conditions and may only be detected over lengthier periods of longer recording of user interactions than are typically available from traditional laboratory usability testing sessions.

Thus, the naturalistic nature of the method allows researches to uncover patterns between issues that might not have been found through other types of usability evaluations. Another advantage of this method is the ability to uncover long-term changes to work patterns, which could be of value to future improvements to a given system.

Furthermore, the method used is relatively unobtrusive for the organization where the evaluation is carried out when compared to other naturalistic evaluation methods e.g. in-situ interviews and observations. The advantage of this is that the results of the evaluation will be less biased by the evaluators presence and thereby forego the say-do problematic of other evaluation methods. The unobtrusive nature of the method also becomes important when conducting naturalistic evaluations in a working environment where interruptions might have a negative impact on the work being carried out e.g. interrupting patient care in EDs.

In addition, the cost for carrying out the study was minimized by using free screen recording and digital video annotation software. Overall we feel the approach could serve as an important complement to traditional usability testing methods, and that it can be carried out in a cost-effective manner. Furthermore, it will uncover errors that may not be detected from short-term rapid usability testing prior to release (i.e. issues that may only be identified over longer periods of time under real conditions of system use).

However, the method applied in the study is not without limitations. In this study we were unable to record any audio while recording interactions. Clinicians thinking-aloud while using the system during this study might have captured some utterances of relevance for the analysis of the data, however this was not practically possible for longer-term recording of user interactions in real-life busy ER departments.

Also, when applying this method it becomes the evaluator's responsibility to determine what constitutes an issue. This is different from other evaluation methods e.g. use of think-aloud protocol analysis where it is often the user who indicates they are having a problem in using the system [19]. This disadvantage is especially relevant in situations where the issues found are related to internal cognitive processes of the user. In such cases the evaluator might unknowingly infer issues that are non-existing for the user e.g. confusion regarding tasks, menu item placement and the meanings of icons. It is less relevant when the issues found are related to visible aspects of the system e.g. system bugs, complicated pathways and issues that end up invoking error messages.

There are also practical considerations when applying the method. One problem that we faced during the study was that the recordings were interrupted due to technical problems or users logging in and out of the workstations and cutting off the recording. Following a regular routine of checking the recordings throughout each recording session can mitigate this issue but it could still be a potential issue when conducting recordings at multiple points as we did. Also, the method is time consuming in terms of analysis making it less applicable for quick usability evaluations and more relevant for longer evaluations of system deployments. The initial data analysis is time consuming since each video file recorded must be viewed at least once in near real time pace (however, using video annotation and time-stamping tools the analysis time was reduced once the digital video files were initially marked up)

Finally, there are certain challenges when applying the method described in this paper. One challenge is caused by the naturalistic nature of the method. When applying this method the evaluator does not have any influence on what the results of the evaluation will show, as is the case with other evaluation methods e.g. usability testing involving think-aloud protocol analysis or clinical simulations where the tasks to test the system are predetermined by the investigators. This presents a challenge for the evaluators when analyzing the results since they must let the issues emerge from the data in a grounded, data-driven fashion. Another challenge related to the naturalistic nature of the method is the issue of how much data will be captured in the evaluation. As mentioned in the description of our results there were some differences in the number of entries between the three sessions. The average lengths of the recordings in the three sessions are approximately the same but interrupted recordings or other technical issues arose making it difficult to directly compare sessions in terms of the numbers of entries recorded. Instead, the differences may have been caused by differences in how busy the EDs have been during the three sessions or how often the selected access points were used throughout the recordings. This poses a challenge for the evaluator when selecting the points for recording and when analyzing the data from the recordings. In this case we chose to compare the percent-wise distribution of the occurring problems to overcome this challenge.

5. Conclusions

Using continuous screen recordings of user interactions with an EW system at two EDs we applied a longitudinal and naturalistic approach to studying the usability issues related to the usage of this system. Through the application of the approach and the analysis of the resulting recordings we found a wide range of system related usability issues that did not appear to change over time as the collective experience of the users at the different EDs increased. However, we found that certain work patterns related to different tasks did in fact change as the departmental experience with the EW system increased. In one work pattern we found that the users appeared to become more efficient with the EW system, which indicated that despite potential efficiency issues in the initial stages of use users have the ability to overcome these issues and learn to use the EW efficiently. In another work pattern we found that the users became less efficient as the department gained more and more experience with the EW system. We argue that a mismatch between this work pattern and the work practices of the ED coupled with the clinician's possibly forgetting the functionality of the EW as they move further and further away from the initial stages of usage could cause this decrease in efficiency. This indicates that some aspects related to the use of the EW need to be continuously refreshed for the users in order to mitigate such issues. This is an area we are planning on investigating further.

Through the study we also gained experience with the application of the methodology applied. We found that the method affords a number of advantages over more traditional usability evaluation methods. We especially find that the longitudinal and naturalistic nature of the method provides researchers and usability evaluators with a tool to uncover issues that would be difficult to reveal with other methods e.g. the ability to expose usability issue that occur very infrequently or only under very specific conditions that can be difficult to predict using more traditional evaluation methods.

However, the application of this methodology is not without limitations, disadvantages and challenges. Some of these are inherent in the methodology and can therefore not be avoided when applying the method e.g. time-consuming initial evaluation of digital video data, increased evaluator responsibility and reduced control of the final results. These issues have to be accounted for when analyzing and reporting the results. Others issues could be mitigated by enforcing certain procedures throughout the application of the method e.g. inspecting recordings regularly to avoid interruptions. In conclusion we encourage that more research be focused on longitudinal and naturalistic evaluations of health information systems and we encourage the use and refinement of the method described in this paper with the hope that researchers will continue to improve the systems that keep our hospital running smoothly and safely.

Acknowledgements

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9.4 **Paper IV:** The long and twisting path: An efficiency evaluation of an electronic whiteboard system

Declaration of co-authorship (PhD thesis)

Under Section 12 (4) of the *PhD order**, a declaration on the extent and nature of the relative contributions, signed by the collaborators and the author, must accompany the PhD thesis if the dissertation or parts of it are the result of collaboration.

Co-authors should fulfil the requirements of the Vancouver rules**

1. General information	
Name of candidate	Rasmus Rasmussen
Title of PhD thesis	Electronic Whiteboards in Emergency Medicine: Studies of implementation processes and user interface design evaluations

2. This co-author's declaration applies to the following article/manuscript No.
Rasmussen, R., and Kushniruk, A., 2012. The long and twisting path: An efficiency evaluation of an electronic whiteboard system. Accepted for publication in proceedings of the 2013 ITCH conference

The extent of the candidate's contribution to the article is assessed on the following scale:

A. has contributed to the work (0-33%)
B. has made a substantial contribution (34-66%)
C. did the majority of the work (67-100%)

3. Declaration of the individual elements	**Extent (A, B, C)**
1. Formulation in the concept phase of the basic scientific problem on the basis of theoretical questions, which require clarification, including a summary of the general questions, which it is assumed, will be answered via analyses or actual experiments/investigations.	C
2. Planning of experiments/analyses and formulation of investigative methodology in such a way that the questions asked under (1) can be expected to be answered, including choice of method and independent methodological development.	C
Involvement in the analysis or the actual experiments/investigation.	C
Presentation, interpretation and discussion of the results obtained in the form of an article or manuscript.	C

4. Co-authors' signatures			
Date	Name	Title	Signature
Jan. 14, 2013	Andre Kushniruk	Professor	

5. Candidate's signature

The declaration of co-authorship should be submitted with the PhD thesis to the Doctoral School.

*The Danish *Ministerial Order on the PhD Programme at the Universities (PhD order),* no. 18 of 14 January 2008

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The long and twisting path: An efficiency evaluation of an electronic whiteboard system

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Abstract. Electronic whiteboard systems are becoming increasingly popular as replacements for the dry-erase whiteboards previously used for communication and workflow coordination at Emergency Departments. With this it also becomes increasingly important that these systems do not disrupt or delay the working practices of the departments where they are taken into use. Usability evaluations should therefore be employed as part of developing and implementing these systems. We report on a subset of the results from a larger usability study of a electronic whiteboard and find that there are inefficiencies, which could be mitigated by a relatively simple redesign and thus improve the usability of the system.

Keywords. Electronic whiteboards, usability evaluation, efficiency, GOMS-KLM

Introduction

Electronic whiteboard systems (EW) are becoming increasingly popular as replacements for the ubiquitous dry-erase whiteboards used for communication and workflow coordination in emergency departments (ED) [1]. However, with this increase in popularity it becomes ever more important that these EWs do not disrupt or delay the working practices of the EDs where they are taken into use. Usability evaluations should therefore be conducted as part of developing and implementing these systems to uncover any potential usability issues. In this paper we report on a subset of the results from a larger usability study performed as part of an evaluation of a specific EW system at two Danish EDs. The focus of this paper will be on efficiency, which refers to the number of resources needed to complete tasks with a system and which constitutes a key aspect of usability [2]. For example, high efficiency occurs when minimal steps are required to complete a task using a system such as an EW. In this paper we explore the analysis of data collected from real users working with an EW system over time in order to determine if inefficiencies can be identified leading to proposed redesigns developed based on the analysis.

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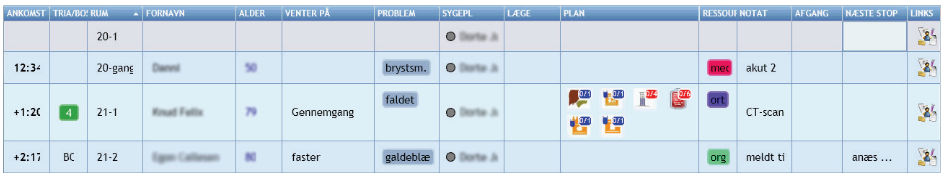

Figure 1: Screen shot cutout of the EW system's user interface

1. Methods

The usability study was performed as a longitudinal and naturalistic study of the ED clinicians' interactions with the EW system. The study involved continuous and long-term screen recordings of the clinicians' interactions with the EW system throughout multiple five-hour periods during dayshifts at two EDs. The healthcare region and ED management approved the study prior to it being conducted. Also, because the study involved collection of live patient data the study had to be registered and approved by the Danish Data Protection Agency. Clinicians on duty during the study were briefed during morning meetings and throughout the study if questions or concerns arose.

1.1. The Electronic Whiteboard

The EW system is a web-based application installed on a central server and is accessible from all web-enabled devices connected to the same network as the server, e.g. laptops, workstations and wide screen displays. The system displays patient related information relevant for coordinating workflow and patient care e.g. name, age, medical problem, triage levels, attending nurse and physician, lab results, etc. Figure 1 presents the general information structure using a matrix with rows for patients and columns for patient data.

1.2. Procedure and Materials

User interactions with the EW were captured using the HyperCam 2 screen capture software installed on 4 Gb flash drives. The resulting video files were stored on either an external 2 Tb hard drive or a 16 Gb flash drive. User interactions were captured over a period of five days between 10 AM and 4 PM each day at two EDs. This period was specifically chosen because experience proved this was often the busiest time of the day and should therefore produce the highest number of interactions with the EW.

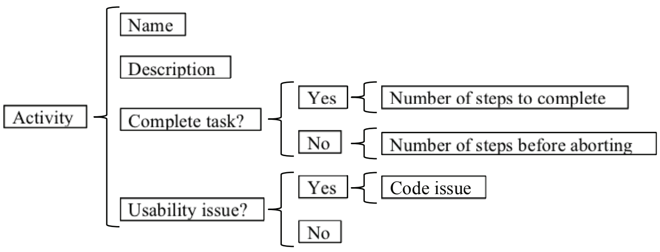

Figure 2: The coding scheme used for logging on-screen activities

The recordings rotated between different workstations throughout the departments and the wide-screen displays located in the ED command rooms. Finally, the first-author was present at the departments during the study to carry out concurrent observations and in-situ interviews with users of the EW system and to administer the recordings.

1.3. Data Analysis

Each video file was viewed and logged by the first-author using a predefined coding scheme developed by both authors – see Figure 2. The initial viewing and logging was carried out solely by the first-author due to restrictions imposed by the Danish Data Protection Agency's directives. Using the coding scheme, on-screen activity was recorded and entered as entries in separate log files. Each entry contains a timestamp, an activity indicator, a name for the activity and a description of the activity. In instances of task oriented activity the entries indicate whether or not the task was completed and the number of steps taken before completing or aborting the task. When usability issues were discovered we marked them with an indicator and coded the issues using one of the following categories: System bugs, efficiency problems, error messages and work patterns. We also provided a description of the issue including whether or not the user solved the issue.

Following the logging process both authors perused each log file and coded activities of interest for further analysis. All codings were discussed to mitigate biases in the analysis. The initial coding of the data was used to locate particular interactions of interest that were further analyzed to identify efficiency issues. In this paper we focus on the analysis of potential inefficiencies. This involved using the GOMS-KLM method [3] to calculate how much time a theoretical expert user would spend on completing a task with the EW system following a specific pathway determined by the original system design.

Based on these analyses, our approach then involves proposing a redesign aimed at improving the efficiency for that task, calculating how much time an expert user would spend using this design before finally comparing this with the GOM-KLM calculations for the original design.

2. Results and Discussion

We logged a total of 2863 entries and recorded 13 unique usability issues: 4 system bugs (55 instances), 4 efficiency issues (141 instances), 3 error messages (38 instances) and 2 inefficient working patterns (229 instances). The most common efficiency issues found in the results concerned complicated and long pathways, which the EW system forces the users to follow when using the system for specific tasks. This issue occurred a total of 63 times (44.68 % of all instances of efficiency issues) in the results. The complicated and long pathways become very apparent when new patients are added to the EW or when certain information fields are updated. In logging the video files we found that adding a new patient on average took 12.3 steps to complete. When users completed this task error free e.g. without mistakes or interruptions and provide the maximum amount of information the task required 19 steps to complete. These steps are the following: **1)** Open "Add row" dialog box **2)** Open "SSN" dialog box **3)** Input SSN **4)** Close "SSN" dialog box **5)** Open "Note" dialog box **6)** Type note **7)** Close

“Note” dialog box **8)** Open “Problem” dialog box **9)** Open problem selection dialog box **10)** Search/select problem **11)** Close selection dialog box **12)** Close “Problem” dialog box **13)** Open “Waiting for” dialog box **14)** Select waiting for option **15)** Close “Waiting for” dialog box **16)** Open “Location” dialog box” **17)** Select location option **18)** Close “Location” dialog box **19)** Close “Add row” dialog box. As this indicates the current design of the EW is based on individual dialog boxes for input into each information field. In the following, we will use the add-patient task as an example to demonstrate how the efficiency of the EW design could be improved via a simple redesign. Using the GOMS-KLM method [3] we are able to calculate how much time a theoretical expert user of the EW system would spend on completing the add-patient task (see Eq. (1) where H = moving hands between mouse and keyboard, P = pointing to a position on the display, K = tapping a key or button, M = mentally preparing for next step – see [3] for definitions of the GOMS-KLM operators). Assuming that the user starts the task with hands off the keyboard, that there is no system response time and that the user inputs a 10-digit SSN and a 30-character note the calculations will be as follows:

$$\begin{aligned}&\mathrm{H+M+P+K+M+P+K+H+M+(K*10)+H+M+P+K+P+K+H+M+(K*30)+}\\&\mathrm{H+M+P+K+M+P+K+M+P+K+M+P+K+M+P+K+M+P+K+M+P+K+}\\&\mathrm{M+P+K+M+P+K+M+P+K+M+P+K+M+P+K+M+P+K=}\\&\text{time spent in seconds}\end{aligned} \tag{1}$$

When replacing the operators in Eq. (1) with the times they represent (H= 0.4 seconds, P = 1.1 seconds, K = 0.2 seconds and M = 1.35 seconds) we find that a theoretical expert user would spend 56.4 seconds on completing the add-patient task when following the pathway that the system currently enforces. The amount of input information needed to complete the task is independent of the pathway followed and therefore cannot be reduced by redesigning the interface. However, by reducing the number of steps needed to complete the task it is possible to make the interface more efficient than the current. We will demonstrate this by proposing a theoretical interface design where the input information is entered directly in text fields or by selection via drop-down menus instead of opening new dialog boxes for each individual input. Once again we assume that the user starts the task with their hands off the keyboard and mouse, that there is no system response time and that the user inputs a 10-digit SSN and a 30-character note. In this case we have the following steps for the task: **1)** Open "Add row" dialog box **2)** Select "SSN" input field **3)** Input SSN **4)** Select "Note" input field **5)** Input note **6)** Select "Problem" option from drop-down menu **7)** Select "Waiting for" option from drop-down menu **8)** Select "Location" option from drop-down menu **9)** Close “Add row” dialog box. When applying the GOMS-KLM calculations to the proposed redesign we arrive at Eq. (2):

$$\begin{aligned}&\mathrm{H+M+P+K+M+P+K+H+M+(K*10)+H+M+P+K+H+M+(K*30)+H+}\\&\mathrm{M+P+K+M+P+K+M+P+K+M+P+K}=31.25\text{ seconds}\end{aligned} \tag{2}$$

Thus, it would take an expert user of the EW system 31.25 seconds to complete the task of adding a new patient when using the proposed redesign of the systems interface. This simple redesign of the EW interface thereby presents a reduction of the theoretical task completion time by 25.15 seconds (44.6 %). Taking into consideration that each ED receives approximately 40.000 – 45.000 patients each year a redesign of this pathway could prove to be a significant time saving improvement over the current design. In a conservative estimate the clinicians provide the maximum amount of information for a new patient for every second patient admitted to the EDs and added to the EW. This leads to a time saving of 157.2 hours each year for this task alone. In cases where the clinicians do not provide the maximum amount of information this time saving will be smaller but still noticeable. Furthermore, since adding patients to the EW is not the only task where the system enforces longer than necessary pathways, a redesign of the input method used throughout the EW system's interface could even further increase the amount of time saved when using the system.

Whether or not the proposed redesign would in fact translate to actual time saving if taken into everyday use is of course a matter of further researcher and experimentation. However, previous evaluations using variations of GOMS methods have proven that these calculations are often precise [4] and therefore we feel assured that our proposed redesign would in fact provide the calculated time saving benefits.

3. Conclusions

Through our usability evaluation of the EW system we found a wide range of usability issues in the EW system. In this paper we chose to focus on long and complicated pathways within the EW system. Using the GOMS-KLM we illustrated with an example how the system could be redesigned to increase its efficiency. We found that our proposed redesign could reduce the time needed to enter a new patient to the EW by roughly 45 % and with the reservation that the clinicians do not always provide the maximum amount of information we found that this could provide a time saving of 157.2 hours pr. year. Also, since the EW system can be accessed via multiple devices the potential increase in efficiency could be far ranged and have a positive impact upon the work practices at the ED. Furthermore, we argued that this redesign could have an even greater impact than our results show since it could potentially affect a larger part of the EW than we studied here. In conclusion we call for more and earlier usability evaluations of healthcare information systems such as the EW studied here to ensure a higher quality of the systems used by healthcare professionals.

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9.5 **Paper V:** Visualizing the application of filters: A comparison of blocking, blurring, and colour-coding whiteboard Information

Declaration of co-authorship (PhD thesis)

Under Section 12 (4) of the *PhD order**, a declaration on the extent and nature of the relative contributions, signed by the collaborators and the author, must accompany the PhD thesis if the dissertation or parts of it are the result of collaboration.

Co-authors should fulfil the requirements of the Vancouver rules**

1. General information	
Name of candidate	Rasmus Rasmussen
Title of PhD thesis	Electronic Whiteboards in Emergency Medicine: Studies of implementation processes and user interface design evaluations

2. This co-author's declaration applies to the following article/manuscript No.
Rasmussen, R., and Hertzum, M., 2012. Visualizing the application of filters: A comparison of blocking, blurring, and colour-coding whiteboard information. Submitted for publication to the International Journal of Human-Computer Studies

The extent of the candidate's contribution to the article is assessed on the following scale:

A. has contributed to the work (0-33%)
B. has made a substantial contribution (34-66%)
C. did the majority of the work (67-100%)

3. Declaration of the individual elements	**Extent (A, B, C)**
1. Formulation in the concept phase of the basic scientific problem on the basis of theoretical questions, which require clarification, including a summary of the general questions, which it is assumed, will be answered via analyses or actual experiments/investigations.	C
2. Planning of experiments/analyses and formulation of investigative methodology in such a way that the questions asked under (1) can be expected to be answered, including choice of method and independent methodological development.	C
Involvement in the analysis or the actual experiments/investigation.	C
Presentation, interpretation and discussion of the results obtained in the form of an article or manuscript.	B

4. Co-authors' signatures			
Date	Name	Title	Signature
24/01-2013	Morten Hertzum	Associate Professor	

5. Candidate's signature

The declaration of co-authorship should be submitted with the PhD thesis to the Doctoral School.

*The Danish *Ministerial Order on the PhD Programme at the Universities (PhD order)*, no. 18 of 14 January 2008

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Visualizing the Application of Filters: A Comparison of Blocking, Blurring, and Colour-coding Whiteboard Information

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Abstract. Through a mixed-design experiment we compare how emergency-department clinicians perform when solving realistic work tasks with an electronic whiteboard system where the application of information filters is visualized either by blocking, colour-coding or blurring information. We find that clinicians perform significantly faster and with less effort and temporal demand when using the blocking interface. However, we also find that the colour-coding interface provides clinicians with a better overview of the information displayed by the electronic whiteboard. The blurring interface did not perform as well as previous research has shown and we discuss the differences between these results and ours. Finally, we find that the clinicians worked much less in parallel than we had expected and discuss the reasons for this.

Keywords: information visualization; filters; colour-coding; semantic depth of field; electronic whiteboards

1 Introduction

The visual information-seeking mantra "*Overview first, zoom and filter, then details on demand*" proposed by Shneiderman (1996) has become a widely used guideline for designing information visualization (IV) interfaces. While much research has focused on designing interfaces that cater to a smooth progression through the steps in the mantra – from an initial overview to selected details (Ahlberg and Shneiderman, 1994; Card et al., 1999; Plaisant et al., 1996, Williamson and Shneiderman, 1992), we focus solely on the second step of the mantra, specifically on how to visualize the application of filters.

Normally, the application of a filter is visualized by showing only the information that passes through the filter. This approach appears natural in many situations but may be unsuited to situations in which the filtered-away information provides a background important to the interpretation of the focal information and to situations in which multiple people simultaneously use a shared interface for related but different purposes. Simultaneous use of a shared interface is, for example, common in emergency departments (EDs) where electronic

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whiteboards provide information pertinent to the clinicians' parallel coordination of their fast-paced, interrelated activities (Aronsky et al., 2008; Bisantz et al., 2010, Bjørn and Hertzum, 2011). This study concerns filtering on such emergency-department whiteboards. Though the clinicians' interactions with the whiteboards are mainly brief they are also numerous and should preferably not prevent other clinicians from reading the whiteboard information they need for their activities. To avoid that one clinician's application of a filter makes the filtered-away information unavailable to other clinicians we investigate visualizing filters by means of colour-coding, which emphasizes the focal information and leaves filtered-away information unchanged, and semantic depth of field (SDOF) (Kosara et al., 2001), which deemphasizes filtered-away information by blurring it but no more than it remains distinguishable. In short, the purpose of this study is twofold:

- To compare ED clinicians' performance on whiteboard tasks when filters are visualized by blocking (the normal approach), colour-coding, and SDOF.
- To investigate whether blocking, colour-coding, and SDOF are differentially affected by whether the clinicians work individually while solving whiteboard tasks or a pair of clinicians share the whiteboard.

The empirical basis for this study is an experiment in which actual emergency-department clinicians solve realistic tasks on a whiteboard similar to the one they use in their real work, except for the variation in how the application of filters is visualized. The whiteboard presents pertinent information about current and reported patients, about the responsibilities of the physicians and nurses on duty, and about the load of the emergency department. Whereas much information-visualization research focuses on large information spaces (Card et al., 1999; Isenberg et al., 2011), the whiteboard is a moderately sized information space and the *overview first* step of the visual information-seeking mantra is therefore relatively easy to accomplish. However, the rapidly changing nature of the information makes the *zoom and filter* step important because the clinicians need to interact with the information at the same pace as changes occur and need to focus on specific parts of the information whilst still being aware of the contextual information surrounding their current focus. Whiteboard information is often read by looking over the shoulder of a colleague who is interacting with the whiteboard. Such shared access to a system for the purpose of solving individual tasks extends current research on multi-user information visualizations, which tends to focus on how visualizations may support collaborative tasks (Isenberg et al., 2011; Mark et al., 2002, 2003).

2 Related work

In their review of IV techniques, Cockburn et al. (2008) distinguish between techniques that use a spatial separation between focal and contextual information, a temporal separation, a seamless separation, and cue-based techniques. The way filters are conventionally visualized they are a temporal-separation technique, while colour-coding and SDOF are cue-based techniques.

2.1 Filtering as a temporal-separation technique

In elaborating the *zoom and filter* step of the visual information-seeking mantra Shneiderman (1996) explains filtering like this: "By allowing users to control the contents of the display, users can quickly focus on their interests by eliminating unwanted items." That is, the application of a filter introduces a temporal separation between the contextual information, which is blocked by the filter and thereby ceases to be visible, and the focal information, which passes through the filter and remains visible. The removal of the contextual information creates additional space for displaying the focal information and, thereby, possibilities for displaying it at a finer level of detail or with less need for scrolling. Animation is frequently used to help users assimilate the transition from before to after the application of the filter and has been found not to increase the time to complete tasks (Bederson and Boltman, 1999). An influential interface control for the application of filters is dynamic queries (Ahlberg and Shneiderman, 1994), which couple users' adjustments of sliders and buttons to rapid and dynamic display updates. The tight coupling between slider adjustments and display updates is another way of helping the user assimilate the transition associated with the application of filters. Prominent examples of dynamic queries include Homefinder (Williamson and Shneiderman, 1992), Filmfinder (Ahlberg and Shneiderman, 1994), and Lifelines (Plaisant et al., 1996).

Several previous studies have investigated the possible costs of the temporal separation between contextual and focal information, with mixed results. Nekrasovski et al. (2006) find that users solve tasks faster with a pan-and-zoom interface, which temporally separates focal from contextual information, than with a focus+context interface, in which contextual information remains visible when focal information is shown. The pan-and-zoom interface also required less mental effort. Similarly, Kobsa (2001) finds shorter task completion times and higher task solution rates for two temporal-separation interfaces than for a focus+context interface. Contrary to these studies, Baudisch et al. (2002) find that users solve tasks more quickly with a focus+context interface than a pan-and-zoom interface. Finally, Hornbæk et al. (2002) compare two pan-and-zoom interfaces: one with an overview of the entire information space, the other without an overview. Users perform similarly with the two interfaces but overwhelmingly prefer the interface with the overview. It appears likely that the experimental tasks may partly explain these mixed results by creating situations in which an understanding of the focal information is differentially dependent on contextual information.

2.2 Colour-coding and SDOF as cue-based techniques

The application of a filter can also be visualized by altering how objects are rendered, that is by adding specific visual cues to them. Such cue-based techniques are most efficient when the cues applied are perceived pre-attentively. Humans perceive and process certain basic features of what is seen pre-attentively and in parallel, including such features as orientation, colour, motion, and stereoscopic depth (Treisman et al., 2010; Wolfe, 2005). Pre-attentive cues can be used to guide a user's attention to parts of a display, thereby highlighting these parts of the display and influencing how the user perceives the display (Treisman et al., 2010; Wolfe, 2005). Importantly, the highlighted parts of the display are shown in context in that the rest of the display remains visible. This may help users stay oriented but also restricts cue-based techniques by neither freeing screen space for displaying the cues, nor reducing any need for scrolling. Previous research shows that pre-attentive cues can successfully enhance IV techniques (Deller et al., 2007; Healey et al., 1996;) and that they are especially useful for rapid detection of targets and regions (Healey et al., 1996).

Colour is well-established as a pre-attentive cue that makes things pop out (Bertin, 1983; Spence, 2007). This pop-out effect facilitates visual search (Wolfe, 1994; Deller et al., 2007) and is the basis for using colour-coding of the focal information as a way of visualizing the application of filters. A related use of colour-coding is for highlighting the appearance of search terms in texts. Deller et al. (2007) point out that in information rich displays colour intensity is important to the use of colour as a pre-attentive cue because intensity can be used to indicate the degree of relevance to the user's search. However, Deller et al. (2007) also mention that the use of colour as a pre-attentive cue may distort the visual appearance of displayed objects or create confusion between the applied colour and coloured display objects.

Drawing on the concept of Depth of Field from cinematography and photography Kosara et al. (2001) have created a visualization technique in which the sharpness of an object indicates its relevance rather than its distance. By blurring irrelevant information this SDOF technique pre-attentively draws the user's attention to the parts of the information space that are still in focus. The degree of blurring is determined by a Degree of Interest (DOI) function, which quantifies how relevant the information is to the user. However, Kosara et al. (2002b) find that users have difficulties distinguishing between multiple levels of blurriness. This suggests the use of a binary DOI function where information is either relevant and in focus or irrelevant and therefore blurred. A further argument for a binary DOI function, especially in relation to collaborative visualizations, is that the perception of how blurred something is depends on the distance at which it is viewed (Giller et al. 2001).

Giller et al. (2001) and Schrammel et al. (2003) incorporated SDOF in a text editor and evaluated how searching for information in a text document with SDOF compared to searching with colour-coding of search terms and to searching without any highlighting of search terms. Searching with SDOF and colour-coding was equally efficient. In a second evaluation Giller et al. (2001) compared SDOF with orientation as methods for users to explore and interpret scatterplot data. SDOF resulted in faster performance and more accurate task solutions than using the orientation method. Finally, it appears that SDOF can be combined with other pre-attentive cues without increased cognitive demands on the user (Giller et al., 2001).

2.3 Shared workspaces and information visualization

In a study of the dynamic nature of cooperative work at a hospital surgery ward Bardram (1998) finds that work at hospital wards can be divided into three levels: co-ordination, co-operation, and co-construction. At the co-ordination level the staff members on a ward work with their individual assignments in the pursuit of fulfilling the purpose of the ward, for example nurses perform nursing tasks and physicians perform physician tasks in the interest of caring for patients. At the co-operation level staff members work together on a specific assignment to fulfil the ward's purpose, for example nurses and physicians work together on a shared task. At the co-construction level staff members reconstruct their working practices in a collaborative manner, for example by discussing the rationales behind certain practices and adapting them to new situations. In their study of whiteboard use in Emergency Departments Bjørn and Hertzum (2011) find that the work practices at such departments are characterized by interdependent work tasks carried out individually by members of heterogeneous staff groups, resembling the co-ordination level found by Bardram (1998).

The co-ordination level of hospital work corresponds to the collaborative style labelled *independent* by Bederson et al. (1999) in their study of single display groupware. It is noteworthy that working independently was the style employed most frequently by the pairs of users in the study by Bedersen et al. (1999) and that this was the case in the condition with one input device as well as in the condition with two input devices. In spite of the frequency with which single display groupware is used by multiple users who work independently, most research has focused on users who work together on a shared task (Isenberg et al., 2011; Mark et al., 2002, 2003). Isenberg et al. (2011) emphasize a shared task to the extent of excluding working independently from their definition of collaborative visualization.

Only a few studies mention scenarios where users work in parallel with multi-user IV systems. Tobiasz et al. (2009) describe an IV interface that allows multiple users to work both independently and jointly while completing data analysis tasks. The users can create individual workspaces and view information in different views according to their individual preferences. The users can also share views and collaborate directly on tasks or they can simply view the other users' workspaces for inspiration. The support for independent work includes that the system allows the users to tailor their individual workspaces independently of other users. Mark et al. (2003) find that users working alone solve tasks faster than users working in pairs. Possible reasons for this finding are, however, not analysed; the analysis instead focuses on differences among the conditions involving pairs of users. Finally, Spotlight (Khan et al., 2005) is a technique for directing collaborating users' attention to a common focal region on a large shared display. Spotlight is distinctly about supporting users who work together, as opposed to independently, but is relevant here because the technique conceptually resembles SDOF by displaying a region of the display normally while the rest of the display is somewhat darkened. Users locate a focal region much faster with Spotlight than when the focal region is indicated by the position of the cursor (Khan et al., 2005).

3 System description

The emergency-department electronic whiteboard (EW) investigated in this study is visually laid out in a matrix-like structure with rows and columns. Each row represents a patient, with columns containing information about, among other things, the patient's name, age, diagnosis, triage level, attending physician,

Figure 1. The emergency-department whiteboard (the names of clinicians and patients in this and the following figures are fictitious).

attending nurse, and time of arrival (see Figure 1). The EW is accessed on a wall-mounted 52” touchscreen. In the experiment all interactions with the whiteboard were through the touch interface.

The whiteboard has two rows of filters. The top row (Figure 2) contains a button for each physician and nurse currently on duty. When a button is tapped the patients shown on the whiteboard are filtered to those attended by the specified physician or nurse. These buttons are used by clinicians to get an overview of their current patients and by the coordinating physician and nurse in assessing and balancing the workload of the clinicians on duty. The lower row (Figure 3) contains four additional filter buttons. Tapping one of these buttons filters the patients on the whiteboard to all patients, those reported but not yet arrived, those arrived and thus in the emergency department, and those in the waiting room. These buttons are mainly used by the coordinating physician and nurse in prioritizing patients, assessing the load of the department, and preparing for the arrival of new patients.

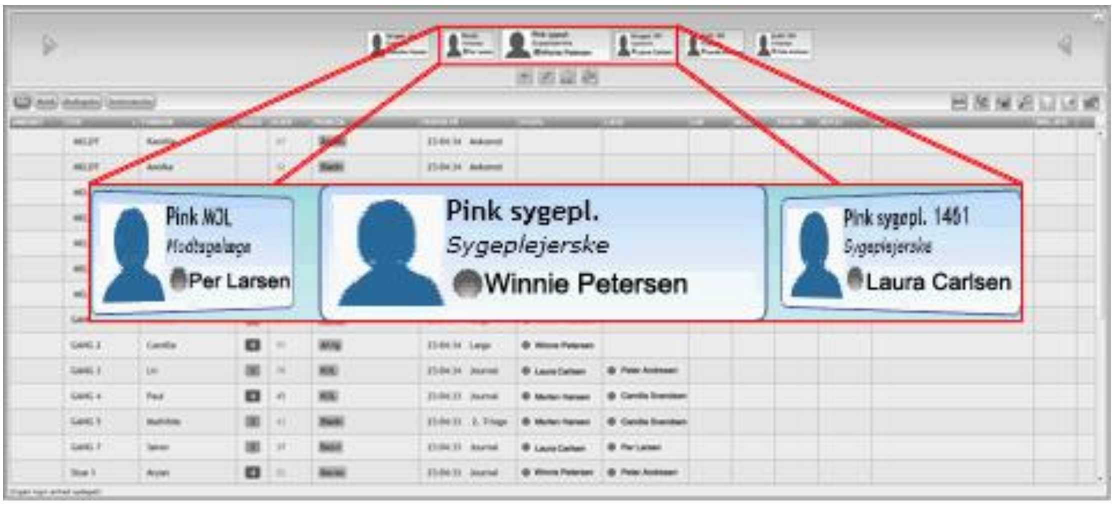

Figure 2. An enlarged image of the filter buttons in the top row.

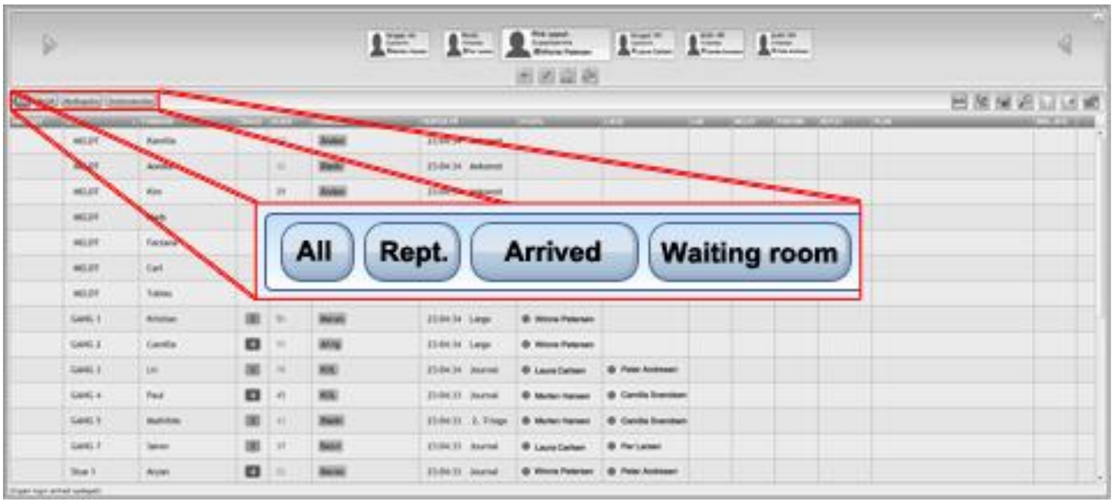

Figure 3. An enlarged image of the second row of filter buttons.

The only difference between the three versions of the whiteboard we use in our experiment is the way the application of a filter is visualized. A filter is visualized in one of three ways:

The *Blocking* interface (Figure 4 top) filters information using the conventional approach of completely removing filtered-away information and leaving focal information unchanged. Because less information is displayed this interface reduces the number of situations in which the list of patients needs a scrollbar.

The *Colour-coding* interface (Figure 4 middle) filters information by darkening the background of focal information, thereby highlighting the focal information. Filtered-away information is not removed but simply left unchanged. Thus, multiple users can read information on the whiteboard even when a filter is applied.

The *SDOF* interface (Figure 4 bottom) filters information by blurring filtered-away information and leaving focal information unchanged. Like in the colour-coding interface this highlights the focal information, while the filtered-away information remains available. The blurring is sufficiently modest that the filtered-away information is still distinguishable for other users viewing the whiteboard.

4 Method

We conducted an experiment to compare the three interfaces on tasks mimicking the normal work practices involving the EW at the ED. Approval for the experiment was obtained from the healthcare region and the management of the ED. The ED was compensated for taking part in the experiment by an amount equivalent to 16 staff hours to be able to call in replacement staff.

4.1 Participants

A total of 18 clinicians (13 female, 5 male) participated in the experiment. The participants comprised nine physicians and nine nurses with an average ED seniority of 4.1 years (*SD* = 5.5). Participants were an average of 38.8 years of age (*SD* = 7.2) and rated their frequency of use of the EW at an average of 7.5 (*SD*

= 5.5) on a scale of 0 (often) to 100 (never). Thus, all participants were regular users of the EW, which had been in use at the ED for approximately 19 months prior to the experiment being conducted. The selection criterion for both profession groups was that they had to have experience as coordinating physician or coordinating nurse. The coordinating clinicians use the EW throughout their shifts and therefore constitute a user group that is highly affected by the ED whiteboard. In the final selection of participants we had to include two physicians without experience as coordinators. However, these two physicians were frequent users of the EW and therefore considered to be acceptable as participants in the experiment. Participation in the experiment was voluntary. The participants took part in the experiment during their working hours and were not compensated individually.

Figure 4. Cutouts from screenshots of the blocking interface (top), colour-coding interface (middle), and SDOF interface (bottom). Each cutout shows the same information filtered according to the nurse named Winnie Petersen.

4.2 Sessions

The experiment involved to types of sessions. In the *individual sessions* a single participant used the whiteboard and could focus exclusively on her or his own task performance. In the *shared sessions* a pair of participants shared use of the whiteboard and had to negotiate how to take turns in accessing it. Each pair consisted of a physician and a nurse. In the individual as well as the shared sessions each participant strictly solved his or her own set of tasks. That is, in the shared sessions the pair of participants were not collaborating but working in parallel on tasks that involved access to a common resource, the whiteboard.

4.3 Tasks and datasets

The experiment involved six tasks, which were repeated for each interface. Based on knowledge collected via interviews with and observation of coordinating physicians and nurses the six tasks were designed to mimic tasks that the participants regularly encountered in their everyday work. Therefore, separate sets of tasks were made for the physicians and the nurses.

For both physicians and nurses there were two types of tasks. The first type concerned the extent to which the three interfaces supported the participants in creating and maintaining an overview of the clinical situation at the ED in terms of arriving patients, waiting patients, and patients undergoing care. There were three tasks of this type. For example, one of the tasks for the nurses read:

> *"Due to one of your nurses wishing to leave early you need to assess the department's collective workload and the future situation. Compare the number of patients admitted to the department against the number of reported patients and decide whether or not you will allow the nurse to leave."*

The second type of task concerned the extent to which the interfaces supported the participants' overview of their colleagues' workload. These tasks consisted of distributing workload evenly across all clinicians. The clinicians' workload could be gauged on the basis of their patients' triage level, diagnoses, age, estimated time of discharge, and other whiteboard information. There were three tasks of this type. For example, one of the tasks for the physicians read:

> *"A new patient has arrived at the department. The patient has been triaged and is now waiting to have a physician assigned. Find the physician you estimate to have the necessary competencies and lowest workload and assign the patient to him or her."*

Six fictive datasets were constructed for the experiment – one for each of the three interfaces in each of the two sessions. The different datasets used for each interface meant that the content of the tasks differed across interfaces though the tasks were the same for all interfaces. This resembles real use, during which clinicians regularly use the ED whiteboard for identical purposes but in situations defined by different patients and ED staffing.

Like the tasks, the datasets were constructed on the basis of interviews with clinicians and observation of ED work. The datasets represented situations of high intensity and workload. We chose such situations to evaluate the interfaces under conditions where the participants need good interfaces to maintain an overview, and we acknowledge that the datasets were not representative of average ED conditions. Also, being fictive the datasets did not include all details regarding the patients. Participants were asked to disregard such omissions. Prior to the experiment, the managing head nurse from the ED reviewed the tasks to ensure their realism and practical relevance.

4.4 Experimental design

The experiment employed a mixed design with interface (Blocking, Colour-coding, SDOF) and session (individual, shared) as within-group factors and profession group (physician, nurse) as a between-group factor. Each participant took part in an individual session and a shared session. Eight participants had the individual session first and the shared session on a later day; the other ten participants had the shared session first and the individual session later. The interval between the two sessions was on average 7.5 weeks. In each session a participant solved the six tasks with each of the three interfaces. To counter order effects, the order of the three interfaces was varied across participants by means of a Latin square.

The six tasks for an interface were solved on the same dataset. The datasets were randomly assigned to interfaces by first assigning three of the six datasets to the interfaces in a pair of participants' shared session and then the remaining three datasets to the interfaces in the two participants' individual sessions. The order of the six tasks for an interface was fixed to establish a flow in the tasks and to ensure that the participants would not be completing similar tasks in close succession.

4.5 Procedure

The sessions were carried out in a quiet room at the ED where the participants worked. In this room the three EW interfaces were available on a 52-inch touch-sensitive display similar to the displays the participants use in their everyday work. When participants arrived for a session they were greeted and allowed to relax before the session proceeded.

Upon initiating the session the participants were handed and asked to read an introductory text explaining the purpose of the experiment and their role in it. Participants gave their informed consent by signing at the bottom of the introductory text. Then, participants were invited to try out the interfaces to become familiar with them. After familiarizing with all three interfaces, the participants were handed and asked to read the definition of the subscales of the NASA task load index (TLX) (Hart and Staveland, 1988) used for measuring mental workload in the experiment.

When ready the participants were handed the first task and asked to solve it as completely and precisely as possible. In the shared sessions, the physician and the nurse received different tasks and solved them in parallel, negotiating access to the interface as they went along. After having solved a task the participants were asked to rate their mental workload, their overview of the information contained in the interface, the ease of use of the interface, and the completeness and precision of their task solution. Then, the next task was handed to the participants. In the shared sessions this did not happen until both participants had completed the previous task, ensuring that both participants started on the new task simultaneously. Upon completing the sixth task for an interface the participants were allowed a short break while the experimenter changed the interface and dataset.

After having completed the six tasks with all three interfaces the participants were asked to rank order the interfaces according to which they preferred to work with and provide their reasons for this ranking. The sessions lasted an average of 42 (individual) and 58 (shared) minutes.

4.6 Measurements

Participants' performance and perception of working with the interfaces were measured for each task. The measurements comprised:

The completeness and precision of task solutions were rated by participants on a scale from agree (0) to disagree (100) in response to statements that the task solution was complete, respectively precise. We chose the participants' perception of solution completeness and precision as indicators of the quality of task solutions because the tasks did not have formally correct solutions against which to measure the participants' task solutions.

Task completion times were logged by the experimenter on a digital stopwatch. A task extended from when the participant had read and understood the task until the participant announced that the task had been completed.

Mental workload was measured using TLX (Hart and Staveland, 1988) which consists of the subscales mental demand, physical demand, temporal demand, effort, performance, and frustration. Participants rated each subscale on a scale from low (0) to high (100), except performance for which the endpoints were good (0) and bad (100).

Overview was rated on a scale from agree (0) to disagree (100) in response to statements that the participant had an overview of the admitted patients, the reported patients, and the staff on duty. We chose these three aspects of overview on the background of observations of and interviews with coordinating clinicians.

Ease of use was rated on a scale from agree (0) to disagree (100) in response to a statement that the task was easy to solve.

Finally, we video and audio recorded the sessions to capture the participants' utterances and how they negotiated access to the interfaces in the shared sessions. A screen recorder captured the participants' interaction with the interfaces. The video and audio recordings were analysed for any matters of interest for our quantitative results.

5 Results

The data were analysed for physicians and nurses, using analysis of variance (ANOVA) with interface (Blocking, Colour-coding, SDOF), session (individual, shared), and profession group (physician, nurse) as independent variables. Before the analyses we removed 24 (4%) outlier tasks, which were more than

1.5 inter-quartile ranges above the upper quartile in task completion time, mainly because the participants commented extensively on how they solved the tasks or on the usefulness of the interfaces for ED work. For an additional 6 (1%) tasks the only available data were the task completion times.

5.1 Task solutions

The physicians and nurses rated the completeness and precision of task solutions highly for all three interfaces – see Table 1. For the physicians we found no effect of interface on the completeness and precision of task solutions and no interaction between interface and session for the completeness and precision of task solutions, $Fs(2, 7) = 0.48, 0.25, 0.85, 1.21$, respectively (all $ps > 0.3$). Also, there was no effect of session on the completeness and precision of physicians' task solutions, $Fs(1, 8) = 0.002, 0.14$, respectively (both $ps > 0.7$).

For the nurses we, similarly, found no effect of interface on the completeness and precision of task solutions and no interaction between interface and session for the completeness and precision of task solutions, $Fs(2, 7) = 1.46, 1.58, 0.71, 0.06$, respectively (all $ps > 0.2$). There was no effect of session on the completeness and precision of nurses' task solutions, $Fs(1, 8) = 0.31, 1.31$, respectively (both $ps > 0.2$).

In addition, there were no differences between physicians and nurses in the completeness and precision of task solutions, $Fs(1, 16) = 0.51, 0.92$, respectively (both $ps > 0.3$), and no interactions between profession group and any of interface, session, and both.

On this basis we contend that the tasks were solved equally well with the three interfaces, in the two types of session, and by the two profession groups.

5.2 Task completion time

Table 2 shows the task completion times. For the physicians there was a significant effect of interface, $F(2, 7) = 8.83$, $p < 0.01$, with Bonferroni-adjusted pair-wise comparisons indicating that Blocking was faster than SDOF ($p < 0.05$) and approached a significant improvement over Colour ($p = 0.06$). Unsurprisingly, there was also a significant effect of session, $F(1, 8) = 9.32$, $p < 0.05$, with lower task completion times for physicians' individual than shared sessions. We found no interaction between interface and session, $F(2, 7) = 1.51$, $p = 0.3$.

Table 1. Task solutions, $N = 618$ tasks

	SDOF		Colour		Blocking	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Physicians						
Completeness of solution	14	9	14	15	13	10
Precision of solution	13	8	13	13	12	11
Nurses						
Completeness of solution	20	13	16	11	15	9
Precision of solution	21	14	17	13	14	9

Note: The completeness and precision of solutions were rated on a scale from 0 to 100 with lower numbers indicating more complete/precise solutions

Table 2. Task completion time (in seconds), $N = 624$ tasks

	SDOF		Colour		Blocking	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Physicians						
Individual	35.6	4.9	40.0	12.5	28.3	11.2
Shared	59.3	20.2	50.3	20.1	47.1	13.7
Nurses						
Individual	38.5	14.0	35.7	11.3	25.5	10.2
Shared	53.5	14.6	57.5	18.8	34.2	11.3

For the nurses there was a significant effect of interface, $F(2, 7) = 15.30$, $p < 0.001$, with Bonferroni-adjusted pair-wise comparisons indicating that Blocking was faster than SDOF ($p < 0.001$) and Colour ($p < 0.05$). Unsurprisingly, we also found a significant effect of session, $F(1, 8) = 5.76$, $p < 0.05$, with lower task completion times for individual than shared sessions. There was no interaction between interface and session, $F(2, 7) = 1.77$, $p = 0.2$.

We found no difference between physicians and nurses in task completion time, $F(1, 16) = 0.59$, $p = 0.5$, and no interaction between profession group, interface, and session, $F(2, 16) = 2.65$, $p = 0.09$.

In an interest to uncover the degree to which the participants utilized the possibility of working in parallel during the shared sessions we calculated, for each participant pair and each task, the sum of the two participants' task solution times from their individual sessions and divided it by the longer of their solution times for the same task in the pair's shared session. Analysis of these ratios showed no significant difference between the three interfaces, $F(2, 7) = 0.75$, $p = 0.89$. However, we found that the mean ratios exceeded 100% for all three interfaces. That is, the time spent by the physician and nurse on solving one task each in their shared session exceeded the sum of the times they spent solving a task each in their individual sessions. Thus, despite the possibility of working in parallel during the shared sessions these sessions were slower than solving the tasks completely sequentially, as in one individual task followed by the other individual task.

To uncover what might cause this increase in task completion times we turned to the videos. The videos showed that participants took turns at the EW to a much larger extent than we anticipated beforehand. In only 15 incidents did we register simultaneous use of the EW by both participants. The video analysis also showed more social interaction during the shared sessions in terms of talk amongst the participants regarding their tasks and insights about how to use or improve the EW. These interactions occurred throughout the shared sessions and also while the participants solved the tasks. Table 3 shows an example with unusually much interaction among the participants during a shared session.

Table 3. Example transcript of a video recording from a shared use session

Utterances:	**Actions:**
	00:06:21 Start of task - Physician starts out using the EW system.
00:06:44 - 00:06:53 **Experimenter:** Remember to use the filter buttons if you feel they could help [solve the task] **Physician:** Yes. But there…	
	00:06:54 Physician continues using the EW to solve task
00:07:15 - 00:07:28 **Nurse:** Can I ask a question? Because it actually says something there - "Waiting for". It's not all there. Does it mean that the patient journal is finished or what does it say - "Patient journal is"? **Experimenter:** It says: "Patient journal is ordered". It should have said "Waiting for patient journal" but [that option was not available]. **Nurse:** Oh okay.	
	00:07:29 Physician continues using the EW to solve the task
00:07:41 - 00:08:25 **Experimenter:** Remember [Nurse] if you feel you can solve your task be simply viewing [the EW] then you are welcome to do so. **Nurse:** I'll just cut in here. **Physician:** Go right ahead. **Nurse:** And that was the one reported as a [triage level] two. But is that then one [of the patients] in the hallway? I am not quite sure… What did you do there? **Physician:** I don't know. I am not used to (using the touch screen). I am used to using the mouse. **Nurse:** I want to use the mouse. **Experimenter:** I can use the mouse. You are not allowed. But you are right [Nurse] – it is that patient. **Nurse:** It was her? Oh okay…	00:07:53 Nurse approaches the EW and starts using the system. Nurse takes over from the physician 00:08:08 Physician fiddles with the EW system's scrollbar causing a generic pop-up box to appear 00:08:14 Experimenter closes pop-up using mouse and keyboard 00:08:20 Nurse leaves the EW system
	00:08:21 Physician continues using the EW system to solve task
	00:08:35 Physician leaves EW system
00:08:35 – 00:11:12 **Physician:** So… I'll say that I would… **Nurse:** Offhand you need more information than what is currently on the EW [to solve the task]. **Physician:** Yes. **Nurse:** It requires that you've spoken with other [staff members] and received some feedback. So it is not only the EW that dictates the solution. **Physician:** I would also like to provide a partial answer. **Experimenter:** Okay. There are these… **Physician:** But our tasks are not related?	00:08:39 Nurse uses the EW system 00:08:43 Nurse leaves EW system

Continues

Continued

Experimenter: No not at all. And there are these [TLX and usability forms]… So if you feel that the tasks have not been solved completely – and that also includes missing external information – you can mark that in these. **Physician:** Oh okay. But if this were a [live situation] then the screen would look different. I would know how long they had been working and I would know when to expect that they were ready and when I could use their resources. I can't see that from this because it doesn't really say anything. I can't see how long they've been working so I can't see when they'll be finished. That makes it difficult for me to solve the task. **Experimenter:** Okay. Sorry to interrupt but have you finished your tasks? Yours is I guess? **Nurse:** Well offhand yes but I am not sure it is the correct answer. Because someone with chest pains could be very very sick so the nurse can't leave. It could also be someone not that ill for example. And you would know that in real life. **Physician:** I would say that if I knew… There are a lot of patients admitted and quite a few reported as well but if all [staff members] currently working are finishing off they could take the next group [of patients] and then it would probably be all right. Some of them are critically ill and there are two yellow down here. So under all circumstances I would enquire an update on how far they are. I should of course check to see if all the physicians available are occupied. I would know that if I had out them to work myself.

00:10:46 Physician approaches the EW and starts scrolling the list of patients

00:11:12 Physician resumes task solving. General/small talk during task solving

00:12:05 Experimenter approaches EW and helps solve technical problem

00:12:23 Physician continues using the EW to solve task

00:13:53 – 00:14:08 **Physician:** So I would say… **Experimenter:** You don't have to write down the answer… **Physician:** Yes. **Experimenter:** If you feel you have the answer then please let me know, so I can stop the timer? **Physician:** Yes. **Experimenter:** Good. Then you get this [TLX and usability form] to fill out.

00:13:52 Physician leaves EW system

00:14:09 Task stopped

Table 4. Mental workload as measured by TLX, $N = 618$ tasks

	SDOF		Colour		Blocking	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Physicians						
Mental demand	25	19	22	17	21	15
Physical demand	21	19	16	9	14	7
Temporal demand	26	18	23	15	22	16
Effort	25	19	22	15	19	14
Performance	19	15	19	16	17	15
Frustration	29	23	22	18	17	15
Nurses						
Mental demand	20	11	18	12	16	10
Physical demand	16	12	16	12	12	8
Temporal demand	26	13	22	12	17	9
Effort	20	11	19	12	15	9
Performance	18	16	19	14	15	10
Frustration	23	14	19	12	13	8

Note: The TLX subscales were rated on a scale from 0 to 100 with lower numbers indicating less demand/less effort/better performance/less frustration

5.3 Mental workload

Mental workload was generally modest – see Table 4. A multivariate analysis of the mental workload of physicians and nurses showed a significant effect of interface, Wilks' $\lambda = 0.41$, $F(12, 54) = 2.49$, $p < 0.05$, with Bonferroni-adjusted pair-wise comparisons indicating that overall mental workload was lower with Colour than SDOF. Bonferroni-adjusted pair-wise comparisons of the individual TLX subscales showed that temporal demand was lower with Blocking than SDOF ($p < 0.05$), that effort was lower with Blocking than SDOF and Colour (both ps < 0.05), and that frustration was lower with Blocking than SDOF and Colour (both ps < 0.01).

There was no effect of session on overall mental workload, Wilks' $\lambda = 0.52$, $F(6, 11) = 1.69$, $p = 0.2$, no interaction between interface and session, Wilks' $\lambda = 0.58$, $F(12, 54) = 1.40$, $p = 0.2$, and no effect of profession group on overall mental workload, Wilks' $\lambda = 0.77$, $F(6, 11) = 0.54$, $p = 0.8$.

5.4 Overview

The clinicians rated their overview of admitted patients, reported patients, and staff on duty as medium – see Table 5. For physicians and nurses combined there were significant effects of interface on the clinicians' overview of admitted patients, reported patients, and staff on duty, Fs(2, 16) = 8.49, 5.59, 6.38, respectively (all ps < 0.01). Bonferroni-adjusted pair-wise comparisons indicated that the overview of admitted patients and staff on duty was better with Colour than with SDOF and Blocking (all ps < 0.05) and that the overview of reported patients was better with Colour than SDOF ($p < 0.05$).

Table 5. Overview, N = 618 tasks

	SDOF		Colour		Blocking	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Physicians						
Overview of admitted patients	51	30	40	30	39	25
Overview of reported patients	52	30	42	27	43	26
Overview of staff on duty	48	30	42	31	39	25
Nurses						
Overview of admitted patients	73	20	43	31	60	27
Overview of reported patients	67	19	43	29	56	25
Overview of staff on duty	69	24	41	32	55	27

Note: The overview dimensions were rated on a scale from 0 to 100 with lower numbers indicating better overview

We found no effect of session on the clinicians' overview of admitted patient, reported patients, and staff on duty (all ps > 0.1) and no interaction between interface and session for any of the three overview variables (all ps > 0.6).

For the physicians the effect of interface on the overview of admitted patients approached significance (p = 0.07), whereas there was no effect of interface on the physicians' overview of reported patients and staff on duty (both ps > 0.1). For the nurses there were significant effects of interface on overview of admitted patients and staff on duty (both ps < 0.05), whereas the effect on the nurses' overview of reported patients approached significance (p = 0.08). Thus, the effects of interface on overview for the physicians and nurses combined were driven by the nurses to a larger extent than by the physicians. We found no interactions between interface and profession group for any of overview of admitted patients, reported patients, and staff on duty (all ps > 0.09).

5.5 Ease of use

The clinicians rated the three interfaces easy to use – see Table 6. For the physicians there was, however, a significant effect of interface on ease of use, $F(2, 7) = 4.46$, $p < 0.05$, with Bonferroni-adjusted pair-wise comparisons suggesting a non-significant trend toward Blocking being easier to use than SDOF (p = 0.1). We found no effect of session on ease of use for the physicians, $F(1, 8) = 0.94$, $p = 0.4$, and no interaction between interface and session, $F(2, 7) = 0.18$, $p = 0.8$.

For the nurses there was no effect of interface on ease of use, $F(2, 7) = 1.64$, $p = 0.2$, no effect of session on ease of use, $F(1, 8) = 1.27$, $p = 0.3$, and no interaction between interface and session, $F(2, 7) = 0.65$, $p = 0.5$.

Table 6. Ease of use, N = 618 tasks

	SDOF		Colour		Blocking	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Physicians	23	18	20	17	16	13
Nurses	22	15	18	12	16	11

Note: Ease of use was rated on a scale from 0 to 100 with lower numbers indicating more ease

5.6 Interface ranking

For the individual sessions, the participants significantly preferred the Blocking interface, $\chi^2(2, N = 17) = 12.82$, $p < 0.01$. As much as 6 physicians and 6 nurses preferred the Blocking interface, 2 physicians and 3 nurses preferred the Colour interface, and no participant preferred the SDOF interface; 1 physician gave no preference.

For the shared sessions, there was no preference for one interface over another, $\chi^2(2, N = 16) = 4.63$, $p = 0.1$. A total of 5 physicians and 4 nurses preferred the Blocking interface, 3 physicians and 2 nurses preferred the Colour interface, and 1 physician and 1 nurse preferred the SDOF interface; 2 nurses did not report a preference.

5.7 Comments from participants

The participants gave several reasons for their preference ranking. In general, the participants favoured the Blocking interface because they were used to working with this interface type. However, they also expressed that the Blocking interface was good for isolating information when that was desired:

> *"I much better like the one we have now [blocking]…. Because it removes something then I don't have a totally confusing screen where I have to scroll up and down. If I only want to see the "Reported patients" then it is nice that I can do that."*

The participants also stated that both the Colour-coding and SDOF interfaces were good for keeping an overview of the entire information space and that this overview was lost when using the Blocking interface:

> *"I especially think the [blurred] one where you don't - and also the other [colour-coded] one in principle. It's just a visual thing. But that you don't lose the overview when you filter something away. That it doesn't just go away. That you still have a sense of how many patients there are. I think that is nice."*

However, the participants also pointed out that both the Colour-coding and SDOF interfaces required a lot of scrolling when the list of patients became very long and that displaying all patients on the same screen could be quite frustrating:

> *"Moreover, I think they are quite frustrating. Both the colour solution and the blurring solution because you have so many on the screen that it becomes impossible to maintain an overview."*

Some participants stated that they disliked the SDOF interface because it made them feel disorientated or try to focus on the parts of the interface that were blurred:

> *"The one where it is blurred - I found that one a little strange. You tried to focus on the parts that were blurred."*

Finally, several participants expressed that they would normally not work in parallel when more users were present at the EW. Instead, they would wait for each other to complete their tasks and then release the EW to the next user in line:

*"**Physician**: It's hard to use the board simultaneously because the tasks are different.*

***Nurse**: Yes*

***Physician**: It would be hard to solve tasks at the same time as you [nurse]*

***Nurse**: But that is often the way it is [physician] right? We stand and wait for […] to be finished*

***Physician**: Yeah, that's just the way it is. We stand and wait…*

***Nurse**: So that's just how our everyday life is."*

6 Discussion

There are four main findings of this study. First, participants solved tasks faster using the Blocking interface (except that for the physicians the improvement of Blocking over Colour merely approached significance). Second, participants perceived that their overview of patients and staff was better when using the Colour interface than the Blocking and SDOF interfaces. Third, among the two cue-based techniques the SDOF interface was more mentally demanding to use than the Colour interface. Fourth, participants virtually refrained from using the EW simultaneously and instead waited for each other to complete their task and release the EW to the next user. We discuss these four findings in turn.

6.1 Blocking is faster

The Blocking interface was faster than SDOF for physicians and nurses and faster than Colour for nurses. For the physicians the improvement of Blocking over Colour approached significance. While participants took longer to solve tasks during shared than individual sessions, the relative advantage of Blocking over the two other interfaces was unaffected by whether participants worked individually or in pairs. The faster performance with Blocking is corroborated by the lower temporal demand perceived by participants when using Blocking compared to SDOF and the lower perceived effort compared to both SDOF and Colour.

A possible reason for the faster performance with Blocking is that by removing filtered-away information the focal information is collected in one region of the interface. For example, applying the filter for a specified nurse removes all patients not assigned to the nurse and, thereby, moves the nurse's patients to the top of the list. By collecting the focal information in one place it may be easier for the user to avoid distractions from other information compared to Colour and SDOF in which the focal information can comprise several regions interspersed by non-focal information. It appears that previous IV work on the possible cost of temporal separation (Baudisch et al., 2002; Hornbæk et al., 2002; Kobsa, 2001; Nekrasovski et al., 2006) has focused on zooming rather than filtering and thereby on visiting relevant regions of a display one region at a time rather than on possibly providing access to multiple relevant regions at a time. Our work suggests that the possibility of collecting scattered focal information in one place may be an advantage that should be considered in assessing temporal-separation techniques.

A related reason for the faster performance with the Blocking interface may be that it provides a tighter visual coupling between the filter buttons and the resultant action of applying one of these, thereby making it immediately clear for the users what happens as a result of applying a filter. This may reduce user confusion when having to differentiate between focal and contextual information displayed by the EW and thereby improve user performance. A third reason for the faster performance with the Blocking interface may be that participants are familiar with this interface because it is the interface of the EW they use in their daily work in the ED. Among the participants who preferred the Blocking interface several mentioned their familiarity with this interface as an explanation.

6.2 Colour-coding supports overviewing

In contrast to the performance times, participants held a better overview of the admitted patients and the staff on duty with the Colour interface than the Blocking and SDOF interfaces. The Colour interface also provided participants with a better overview of reported patients than the SDOF interface. The main reason for the improved overview with the Colour interface appears to be that this interface, and the SDOF interface, did not remove information from the EW. Several participants commented that with the Colour and SDOF interfaces they could maintain an overview even when they applied filters, whereas with the Blocking interface their overview tended to suffer when they applied filters because the non-focal information disappeared.

While the temporal integration of focal and contextual information in the Colour interface improved participants' overview, the amount of scrolling required to navigate the list of patients was not reduced because the focal information remained in its original positions in the list. In addition to frequent scrolling, this also entailed repeated visual scanning of the patient list to skip over the non-focal patients when participants were shifting their attention back and forth among the focal patients. This way, it appears that the Blocking interface optimizes an efficient, undisturbed focus on the focal information, whereas the Colour interface optimizes context awareness while solving tasks with the EW.

A possible way of combining the advantages of the Blocking and Colour interfaces could be to colour-code and resort the patients so that the focal information is relocated at the top of the list and in immediate view while still displaying the remaining information. This eliminates the need for scrolling the full patient list to locate the focal information and preserves an overview of the contextual information. The idea is somewhat akin to how split menus collect the most relevant items at the top of a menu for easy access (Sears and Shneiderman, 1994). A frequent argument against split menus is that the changing location of items slows down selection because it conflicts with users' location knowledge (Fischer and Schwan, 2008). We contend that location knowledge is largely irrelevant in a case like the EW because the content of the patient list is continually changing as new patients are added and discharged patients deleted. The fast performance of the Blocking interface supports that dynamically changing the patients' position in the list does not slow down users. Findlater and McGrenere (2004) find that a split menu in which the users individually and dynamically determined which items to put above the split (as would be the case if item resorting is used for filtering) performed well and was popular with the users. Several of our participants suggested resorting as a possible improvement of the EW interface. For example, one participant commented:

> *"I was thinking... For example - when you select [physician name] - it would be nice if they [patients] moved to the top so you could see them right away. Then it doesn't matter if the others are coloured or blurred. But it would be really nice if they were automatically moved to the top."*

6.3 SDOF is mentally demanding

The SDOF interface imposed higher overall mental workload, as measured by TLX, than the Colour interface. This finding shows, in combination with the reduced overview when using SDOF compared to Colour and the absence of a difference in task completion times between these two interfaces, that the Colour interface was the more usable of the two cue-based techniques. Compared to previous studies, our results for SDOF are less positive. One possible explanation for this difference is that previous studies (Giller et al., 2001; Kosara et al., 2002a, 2002b; Schrammel at al., 2003) have mainly tested users' ability to locate unblurred objects quickly and accurately, whereas our study investigates users' ability to assess a situation by deriving information from multiple unblurred areas and relating it to blurred contextual information. Also, Giller et al. (2001) and Kosara et al. (2002a) made their evaluations with participants who had "very good eye sight", which may benefit SDOF compared to the older and visually more average participants in our study.

One reason for the higher mental workload associated with SDOF than Colour-coding is probably that some participants tried to read the blurred information and found this to be unpleasant and difficult. Kosara et al. (2002b) similarly find that users do not like to look directly at blurred objects and argue that if they do it is an indication that the system is badly designed. We contend that for multi-user visualizations, such as the EW, it is a feature of the design that the blurred information remains distinguishable, especially for the users not currently in charge of navigating the visualization. Thus, we are interested in ways of making the blurred information less unpleasant and easier to look at. An obvious possibility is to reduce the level of blurring. In the SDOF interface the colour indication of the triage level is easily told even when blurred and the names of attending physicians and nurses may also be recognizable because users have good knowledge of their colleagues' names and thus need few cues to be able to recognize them, but the remaining fields of information are difficult to make out when blurred (see Figure 4). However, reducing the degree of blurring increases the risk of creating confusion about whether information is blurred or not. Previous work (Giller et al., 2001; Kosara et al., 2002b) provides little guidance on the degree of blurring required to avoid such confusion. Another way of making blurred information less unpleasant and easier to read could be to darken rather than blur non-focal information, as in the Spotlight system (Khan et al., 2005).

The SDOF interface may benefit even more than the Colour-coding interface from the idea of resorting the patients when a filter is applied so that the focal information is relocated at the top of the list while the remaining patients are still displayed. The resorting would imply that all the focal information would be in one place, producing a visual effect of one unified focal region surrounded by a blurred contextual region. We speculate that with one unified focal region, rather than multiple scattered focal regions, a lower degree of blurring will suffice to tell blurred from unblurred information.

6.4 Users work in turns

In the shared sessions, participants' collaboration in their use of the shared EW was restricted to deciding which participant solved her or his task first and which participant waited for the other to be done and release the EW for the other participant. We registered only 15 instances of simultaneous use of the EW across the 18 tasks solved by each participant in each of the 9 shared sessions.

An important part of the reason for the virtual absence of simultaneous use was that the physician and nurse in a pair had individual tasks, rather than a shared task, and that their tasks required looking into different parts of the information on the EW. Only one participant at a time could navigate the shared EW and make changes to its content. We had however expected that participants would utilize that they could make some progress on their task by simply looking at the EW, also while the other participant was operating it, and that participants would negotiate access to the EW on a subtask-by-subtask basis rather than a complete task at a time. According to several participants the absence of simultaneous use is not an artefact of the study but the way in which they use the EW in their daily work at the ED. This emphasizes the need for collaborative visualizations to support users who work independently, whether they do it temporarily or as a more fixed approach to their collaboration. We still suspect that simultaneous use of the shared EW occurs with some frequency in the participants' daily work, even if only implicitly and not in the fashion we envisioned. Simultaneous use may, for example, be restricted to situations in which the secondary users need neither apply filters nor change the contents of the EW and, thus, can accomplish their full use of the EW by looking over the shoulder of a colleague. Our experimental tasks did not include such use of the EW.

We concur with statements from other researchers (Bederson et al., 1999; Isenberg et al., 2011) that the nature of collaboration in front of shared displays is insufficiently understood. We, for example, find that the pair of participants in a shared session took longer to solve their tasks than the sum of the task completion times for their individual sessions. Thus, even though the participants organized their shared sessions in a serial manner by refraining from making simultaneous use of the EW their shared sessions involved an overhead compared to the duration of one participant's individual session followed by the other participant's individual session. This overhead must, in some way, be a product of the social situation constituted by the shared session. Our analysis shows that the participants talk together about their individual tasks and about how to use the EW. We speculate that the social situation may also prolong the shared sessions in more subtle ways, such as by increased thoroughness due to more motivation to reach good clinical decisions. Our data on the task solutions do, however, not support this speculation in that the completeness and precision ratings of the task solutions are the same for individual and shared sessions.

We find only one difference between individual and shared sessions: While participants preferred the Blocking interface in the individual sessions, they did not prefer one interface over the others in the shared sessions. This result is our only, weak, indication that the costs of removing contextual information rather than visualizing the application of a filter by adding cues to the focal information may be higher in multi-user situations, where different users may need access to different information, than in single user situations.

7 Conclusion

The participants in our experiment completed their tasks significantly faster and with less temporal demand and effort when using the Blocking interface. A likely explanation for this is that this interface collects focal information in a single region of the EW display, thereby eliminating distractions from surrounding information as well as the need to scroll the entire list of patients. The Colour-coding interface provided the participants with the best overview of the EW information. However, because the Colour-coding interface keeps the focal information in its original position when a filter is applied the amount of scrolling needed to navigate the EW is not reduced. As suggested by some participants, a combination of colour-coding and moving the focal information to the top of the patient list may combine the advantages of the Colour-coding and Blocking interfaces.

The SDOF interface imposed higher mental workload compared to the Colour-coding interface. Also, the SDOF interface provided a reduced overview and was not significantly faster or slower compared to the Colour-coding interface. We conjecture that a unified unblurred focal region, for example created by resorting the information, would be easier to locate than multiple unblurred scattered foci amongst blurred contextual information. However, we also conclude that the SDOF interface showed less promise in this study than in previous studies.

Finally, we found that the participants almost completely refrained from working in parallel, probably due to a combination of the tasks solved in the shared sessions and participants' normal way of using the EW in their daily practice. We urge researchers to focus more on investigating the uses of IV techniques for work situations where users may not directly collaborate with each other but instead share access to a system through a common artefact.

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9.6 **Paper VI:** Balancing tradition and transcendence in the implementation of Emergency Department electronic whiteboards

Declaration of co-authorship (PhD thesis)

Under Section 12 (4) of the *PhD order**, a declaration on the extent and nature of the relative contributions, signed by the collaborators and the author, must accompany the PhD thesis if the dissertation or parts of it are the result of collaboration.

Co-authors should fulfil the requirements of the Vancouver rules**

1. General information	
Name of candidate	Rasmus Rasmussen
Title of PhD thesis	Electronic Whiteboards in Emergency Medicine: Studies of implementation processes and user interface design evaluations

2. This co-author's declaration applies to the following article/manuscript No.
Rasmussen, R., Fleron, B., Hertzum, M. and Simonsen, J., 2010. Balancing tradition and transcendence in the implementation of emergency department electronic whiteboards. In: Selected Papers of the Information Systems Research Seminar in Scandinavia, Tapir Academic Publishers, Trondheim, Norway, pp. 73-87.

The extent of the candidate's contribution to the article is assessed on the following scale:

A. has contributed to the work (0-33%)
B. has made a substantial contribution (34-66%)
C. did the majority of the work (67-100%)

3. Declaration of the individual elements	**Extent (A, B, C)**
1. Formulation in the concept phase of the basic scientific problem on the basis of theoretical questions, which require clarification, including a summary of the general questions, which it is assumed, will be answered via analyses or actual experiments/investigations.	B
2. Planning of experiments/analyses and formulation of investigative methodology in such a way that the questions asked under (1) can be expected to be answered, including choice of method and independent methodological development.	B
Involvement in the analysis or the actual experiments/investigation.	B
Presentation, interpretation and discussion of the results obtained in the form of an article or manuscript.	C

4. Co-authors' signatures			
Date	Name	Title	Signature
24.01.2013	Benedicte Fleron	PhD fellow	[signature]
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5. Candidate's signature
[signature: Rasmus Rasmussen]

The declaration of co-authorship should be submitted with the PhD thesis to the Doctoral School.

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Balancing Tradition and Transcendence in the Implementation of Emergency-Department Electronic Whiteboards

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Abstract. We report from a case study of the implementation of an electronic whiteboard system at two emergency departments at Danish hospitals. The purpose of the whiteboards is to support the clinicians in maintaining an overview of the patients at the departments. The electronic whiteboard system was designed in collaboration with clinicians from the departments. Compared to existing dry-erase whiteboards, the electronic whiteboards present more information and allow some automated updating. Based on observations supported by interviews we describe how tradition and transcendence were balanced in the implementation of the whiteboards at the two emergency departments. The electronic whiteboards were initially configured to resemble the dry-erase whiteboards and then gradually reconfigured and extended through an improvisational process, along with changes in the clinicians' work practices.

Keywords: Electronic whiteboards; organisational implementation; improvisational change management; healthcare informatics.

1 Introduction

It has recently been decided to establish emergency departments (EDs) at hospitals throughout the five Danish healthcare regions. Initially, the newly established EDs adopted the manual patient-tracking and coordination systems used in the departments from which the EDs were formed. These systems consisted of a dry-erase whiteboard augmented with a matrix-like information structure used to display patient specific information such as name, age, diagnosis, attending physician/nurse, room number and clinical care plan – see figure 1. As part of the ongoing process of establishing effective and safe work procedures at EDs, it has become a political decision to develop and implement IT-based information systems to replace the previously used manual patient-tracking and coordination systems. This paper reports on such a development and implementation project at two hospitals in Region Zealand.

Previous research has shown that patient-tracking and coordination systems based on dry-erase whiteboards are central to effective and efficient work practices at EDs and hospital departments in general (Lasome & Xiao, 2007; Wears & Perry, 2007; Xiao et al., 2007). There are, however, certain drawbacks to the manual patient-tracking systems compared to the possibilities offered by IT-based patient-tracking and coordination systems (known as electronic whiteboards). Since the dry-erase whiteboards have no possibility of storing information they are at a disadvantage in terms of documentation and data retrieval. Hence, they cannot be used to retrieve information regarding previous patients. Also, the manual tracking systems cannot be accessed in a distributed manner and clinicians, therefore, have to return to the dry-erase whiteboard to view, add, delete or update information. This takes time away from patient care. Real-time tracking of patients and integration with other hospital information systems is also impossible with the manual patient-tracking systems, and this creates a risk of delays and errors in the information presented on the whiteboard. Besides these practical reasons for replacing the manual tracking systems, clinicians at the two EDs have expressed that they expect electronic whiteboards to have a positive impact on their work practices (Hertzum & Simonsen, 2010).

Figure 1: A cut-out of the old dry-erase whiteboard at ED2.

Together these circumstances have led to a region-wide initiative to develop and implement electronic whiteboards at the region's hospitals. In this paper we report from this development and implementation process. Our aim is to investigate how an implementation process can unfold while obtaining an appropriate balance between tradition and transcendence. We adopt the concept pair of tradition and transcendence from Ehn (1988), who concludes that designing IT-based artefacts is a balance between not disturbing the essence of the existing work practices (i.e., tradition) but still changing or improving these practices (i.e., transcendence). Ehn argues that this can be achieved by designing IT artefacts that fit into the existing work practices but at the same time cause breakdowns that force the designers and users to re-evaluate the existing work practices and, thereby, discover new practices and new artefact designs. Balancing tradition and transcendence is particularly important in our case because the traditional dry-erase whiteboards are efficient and well liked by the clinicians, because the new electronic whiteboards are believed to offer important benefits, and because ED work is safety-critical and therefore calls for a cautious implementation process.

In the following we *first* relate our study to previous work. *Second*, we introduce the setting – the overall research project and the two EDs. *Third*, we describe the empirical method employed in the study. *Forth*, we briefly describe the interface design and functionality of the electronic whiteboards implemented at the two EDs. *Fifth*, we describe the implementation process at the two EDs. *Sixth*, we show how tradition and transcendence were balanced through an improvisational implementation process. *Finally*, we discuss and conclude on the implications of our findings for our future work and for the continued development and implementation of the whiteboard.

2 Related work

One way of achieving the right balance between tradition and transcendence may be to follow a development and implementation approach that initially presents a somewhat recognisable system design to the users and, subsequently, allows for spontaneous or improvisational changes to the IT artefact and associated work practices. Thereby, the system respects the users' traditional work practices but drives forward the change process by providing the users with new opportunities or causing breakdowns to the existing work practice. Such an approach is similar to Orlikowski and Hofman's (1997) organisational change-management approach. Orlikowski and Hofman introduced a model for improvisational change management, where they distinguish between three kinds of change that potentially occur when new technologies are introduced to an organisation: anticipated, emergent, and opportunity-based (Orlikowski and Hofman 1997). Anticipated change is planned ahead and occurs as intended by the originators of the change. Patients might, for example, experience less waiting time due to more effective coordination by means of the electronic whiteboard. Emergent change is defined as local and spontaneous changes, not originally anticipated or intended. Such changes do not involve deliberate actions but grow out of practice. Clinicians might, for example, meet less often at the whiteboard due to the possibility to update whiteboard information from any PC at the department. Opportunity-based changes are purposefully introduced changes resulting from unexpected opportunities, events, or breakdowns that might arise after the introduction of a new information system. This could, for example, involve the establishment of new procedures where the physicians, rather than the medical secretaries, update patient information in the system when contacted by paramedics upon arrival of a patient.

The literature about electronic ED whiteboards can be divided into three groups. The first group describes the practical aspects of designing, developing and implementing an electronic whiteboard system (e.g., Abujudeh et al. 2010; Aronsky et al. 2008; Bardram et al. 2006). Much of the literature in this group is based on case studies that detail the design and functionality of different electronic whiteboard systems used in different clinical settings. This literature often details what problems existed with the manual dry-erase whiteboards (e.g., no possibilities of storing old information, lack of distributed access, no real-time updating and no possibility of integration with existing IT systems) and how the electronic whiteboards have been envisioned to overcome these drawbacks. They also often contain brief descriptions of the technical implementation of the systems and their ability to integrate with other clinical IT systems. Finally, the literature also often discusses what advantages the new systems provide the departments. Bardram et al. (2006) also discuss the theoretical aspects of the design of the studied electronic whiteboard and detail how these have been brought into the design.

The second group is also focused on the design, development and implementation of electronic whiteboard systems and presents many of the same findings as the first group. However, the literature in the second group also details what effects the implementation of an electronic whiteboard system has had on different aspects of ED work. This includes positive effects on measurements related to patient treatment such as length of stay, patient satisfaction and similar measurements (Boger 2003; Jensen 2004). This group of literature also finds that electronic whiteboard systems have a positive impact on the communication and coordination of patient care and on employee satisfaction in general (France 2005; Wong 2009).

Finally, the third group focuses on more theoretical aspects of the electronic whiteboard systems (e.g., Bisantz et al. 2010; Fairbanks et al. 2008; Pennathur et al. 2008; Potter 2005). Bisantz et al. (2010) and Pennathur et al. (2008) analyse the changes that occur in the information displayed by patient-tracking systems when shifting from dry-erase whiteboards to electronic whiteboards. These analyses show that the same categories of information are present on both types of system but with substantially different frequency. In particular information used to coordinate the clinicians' work was more frequent on the dry-erase whiteboards. Also, the information on the dry-erase whiteboards was used more dynamically than that on the electronic whiteboards. Fairbanks et al. (2008) detail a usability study of the interface design of an electronic whiteboard. They show that the interface design violates basic usability guidelines and that these violations have potential negative effects on patient safety. Thus, they conclude their paper with call for more emphasis on usability evaluations of these types of system. Finally, Potter (2005) gives an account of how an electronic whiteboard was developed and implemented at one ED and the effects that the system has had on the department. This paper also details the strategy behind the implementation process and finds that staff buy-in is highly important to the successful implementation of such a system.

3 The setting

This study was conducted in the context of a research project that is a collaboration between Roskilde University, Region Zealand, Norwegian IT vendor Imatis and the hospitals of Region Zealand. The overall research project focuses on developing IT-based information systems for supporting the clinicians at the newly established EDs in the region. In the description of the research project this focus is explained as supporting *clinical overview* at two levels: ward level and patient level. Overview at the ward level regards, amongst other things, keeping track of the patient-treatment progress, the number of patients, the clinical resources available (in terms of ED staff, rooms, and equipment), and the resource allocation at any given time. At the patient level, overview is about obtaining and maintaining knowledge regarding the individual patient's condition and about integrating patient information from a range of information sources. The two levels are interrelated, but the present study concerns overview at the ward level.

A total of four EDs are involved in the research project. Two of the EDs, termed 'development departments', are involved in the development and pilot implementation phases. The two other EDs, termed 'research departments', will be involved in studies evaluating the effect of the electronic whiteboards. The present study was conducted at the two development departments – ED1 and ED2. Both EDs were established in the spring of 2009 as independent departments combining a number of previously separate departments into one. The overall rationale for the EDs has been to establish and provide a single point of entry to the hospitals for all acute patients. This includes patients who have been referred to the hospital by their general practitioner, patients who arrive at the department themselves, and patients who are brought to the hospital by ambulance, for example from traffic accidents. The main task of the EDs is to receive these patients, asses their general state of health (triage), diagnose them, start initial treatment and, depending on their state of health, either discharge them or admit them at one of the hospital's specialty departments, such as the medical ward. Table 1 shows the resource allocation for the two EDs.

Allocation of resources	*ED1*	*ED2*
Annual Patient Expectancy	N/A	40,000
Fast-Track No. of Beds/Trauma rooms	5-7/1	4/1
Waiting room	Yes	Yes
Acute No. of Receiving/OBS beds	6/4	10
No. of Acute-medical beds	16	None
No. of Physicians	11	29
No. of Nurses	69	27
No. of Secretaries/Assistants	13	10.5

Table 1: Allocation of resources at ED1 and ED2

ED1 consists of three patient areas: fast track, acute, and acute medical. The fast-track area handles patients that only need a relatively superficial treatment such as stitching cuts or attending a sprained ankle. Patients expected to be transferred to another department or sent home on the same day are handled at the acute area. The acute-medical area receives patients whose total hospitalisation is expected to be maximally two days. ED2 consists of two distinct areas: a fast-track area and an acute area. Both areas resemble the corresponding areas at ED1. At ED1 the chief physicians, nurses, and secretaries are employed directly by the department, whilst the younger physicians are associated with the hospital's specialty departments and brought in on an on-call basis. At ED2 all clinicians are employed directly by the department.

The development and implementation of the electronic whiteboard system has been organised around an *implementation group* with representatives from ED1, ED2, the region and the IT-vendor. Throughout the development and implementation process the implementation group has met about once every second week to plan future development and implementation activities, follow up on progress, correct errors and improve the interface and functionality of the whiteboards. Early on, the main role of the implementation group was to gather user requirements from the clinicians and communicate these requirements to the IT vendor. Subsequently, the implementation group has been responsible for the mutual adaptation of system and work practices, thereby enabling an on-going, iterative, and improvisational change-management process.

4 Empirical Approach

Our methodological approach has mainly consisted of observations and interviews at the two EDs, supplemented with document analyses and partaking in the meetings of the implementation group. Over a period of 1.5 months we conducted 14 observation sessions, each lasting about 7 hours. The observation sessions had different foci depending on which work functions we observed. At each observation session we have been two researchers present, one focusing on the activities in the control room and the other following clinicians on the ward. We did this because we suspected that the influence of the system would in multiple ways depend on the clinicians' role, work function and the need for close contact with either the patient or a colleague. We started by observing the activities at the whiteboard in the control room and the work of the medical secretaries to get an overall understanding of their work practices. The following observations concentrated on the coordinating physician and the triage nurse and were mostly carried out in the control room. In parallel to these observations, we made observations of nurses and physicians by following them around on the ward. Our recordings of these activities comprise about 65 pages of handwritten notes, 30 pages of field diary notes, 15 hours of video, and 40 pictures.

In addition to these observational activities, we collected different artefacts that are used for obtaining an overview, mostly in the form of paper documents. We also conducted two qualitative interviews with a senior clinician from each ED. These two clinicians have been involved in the configuration and implementation of the electronic whiteboards and were interviewed about this process. Finally, during the one and a half months we followed the practices at the EDs we also participated in the meetings of the implementation group. During this period the implementation group worked on adapting the electronic whiteboards and clinical work practices to each other by reconfiguring and extending the electronic whiteboards and by adjusting work practices. We took part in this work.

In analysing our empirical data we focused mainly on the observations and interviews. First, we read through all our observational notes and sorted them into initial categories. These categories included errors in the functionality of the system, breakdowns in work procedures as a result of the opportunities offered by the system, and consequences of the system on the clinicians' ways of obtaining or losing an overview. After categorising our observations, we looked at our diary notes and interviews to see what they told us about the implementation process and, in particular, about the reasons for the differences between ED1 and ED2 in terms of how they approached the implementation process. Combined with our experiences from the implementation-group meetings, the overall theme that began to emerge from the data concerned a recurrent tension between changing too little out of respect for the clinicians' existing work practices and changing too much in trying to exploit the technological possibilities all at once. Following Ehn (1988) we see this tension as an effort to balance tradition and transcendence, and following Orlikowski and Hofman (1997) we see the implementation process devised by the implementation group as an example of improvisational change management.

5 System description

The electronic whiteboard system is web-based and placed on a server outside the hospital. It is accessible through a web-browser, which offers the flexibility of accessing the system from any device with access to the server. It is possible to interface the system with other clinical IT systems, thus allowing automatic updating of the information shown. However, at the time of our study the system was only integrated with the regional social security number (SSN) database and therefore only names and ages were updated automatically. The users can interact with the system through large touch screens in the ED control room, via a mouse and keyboard connected to the PC running the touch screen, or via other PCs connected to the system. The clinicians used all options of interacting with the system but they had a tendency to access the system when they were in the same room as the large touch screens.

5.1 Interface design

The basic layout of the whiteboards is a row for each patient, divided into a number of columns with selected information about the patient – see figure 2. This layout is purposefully copied from the old dry-erase whiteboards to ensure a certain degree of recognisability – see figure 1. The order of the columns follows the average flow of a patient from when (s)he is announced at the ED and until (s)he is discharged.

Figure 2: The electronic whiteboard at ED2. Names are concealed for privacy reasons.

The order of the patients can be rearranged via sorting functions corresponding to the columns. Thus, the patients can be sorted according to their age, name, room number, attending physician/nurse, and so forth. This functionality is especially intended for sorting the patients according to the severity of their condition. The clinicians also have the possibility of filtering the information on the electronic whiteboard using predefined filters. This way the information can be filtered to show only patients in specific patient areas, to show only the patients who have been reported to the ED or to show only the patients in the ED waiting rooms. The system also supports cursor hovering enabling the system to provide additional information when the clinicians hover the cursor over a whiteboard cell. Thereby, it is possible to conceal for example social security numbers or patient surnames and only present these when the cursor is hovered above the corresponding cells.

Above the matrix of patient information is a menu bar showing the on-duty clinicians. For each clinician their name and title are presented as well as their role during the current shift. The system also supports pictures of the clinicians but at the time of our study the clinicians did not yet use this feature.

At the time of our study the main input mechanism was manual input through either the large touch screens or the PCs connected to the electronic whiteboard system. Future versions of the system include automatic presentation of the results of lab test and monitoring of vital signs. The names of the clinicians associated with the ED are stored in an alphabetical list and can be brought out when adding a clinician's name to the whiteboard. The intended clinician is selected by clicking on the field, to which the name is to be added.

5.2 System functionality

In the following we describe how the whiteboard is used for a generic patient trajectory at ED2. The patient trajectory at ED1 is very similar. The description of system is based on our observations, and due to the iterative nature of the implementation process the system functionality may subsequently have evolved.

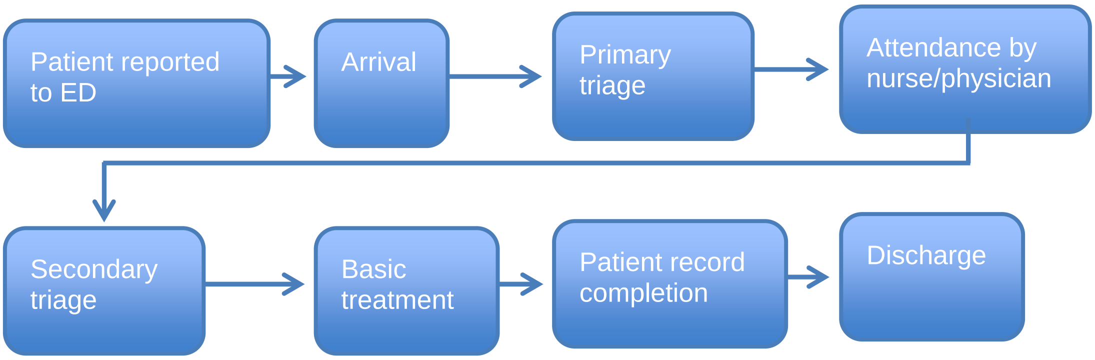

Figure 3: A basic patient trajectory.

A generic patient trajectory is shown in figure 3. Initially, a patient is reported to arrive at the ED. This normally happens via a telephone call from the patient's general practitioner or paramedics in case of an emergency arrival. At this point initial information about the patient is recorded on paper and then typed into the corresponding whiteboard fields by the clinician receiving the call. The patient's social security number is entered into the Age field and based on this the system calculates the patient's age and retrieves his/her name from the SSN database and automatically fills in the name field. If the system cannot retrieve the patient's name the clinicians enter a name manually. The Age field also indicates the patient's gender by colouring the age blue for male and red for female patients. The preliminary health status, diagnosis and vital signs are entered into the Problem, Note and Vital-Signs fields. Additional free-text details about the patient's medical problem or diagnosis can be entered into the Note field. The patient is also set as being 'en route' in the Room field. Finally, the Awaiting field is set to be waiting for the patient's arrival at the ED. This field includes a timer, showing how long the patient has been awaiting the next step in the patient trajectory, which currently is 'awaiting arrival of patient'.

In the case where a patient walks into the department (i.e., patients with minor injuries) the medical secretary receives the information mentioned above and enters it on the electronic whiteboard. The patient is then asked to wait in the waiting room and the electronic whiteboard is updated to show when the patient arrived at the ED and that (s)he is waiting for primary triage.

When a patient arrives by ambulance two actions are carried out: The medical secretary updates the Arrival field with the current time. Simultaneously, the triage nurse assesses the patient’s medical condition and updates the Triage field to reflect this. The information in the Triage field is indicated by a number between 1 and 5 as well as by colour-coding the number. For patients in the waiting room the triage process is identical to the process described above. As multiple patients can have the same triage level there is often a need to prioritise among patients with the same triage level. This can be done in the Priority field. The triage nurse also assigns the patient to a room that suits the patient’s needs (Room field), and decides which nurse will be responsible for the patient (Nurse field). After updating these fields, the triage nurse changes the Awaiting field to show that the patient is now awaiting a physician. This notifies the coordinating physician to take action.

The coordinating physician assigns a receiving physician to the patient by updating the Physician field and notifies the physician about this. Before the physician attends the patient, the Awaiting field is once again updated, this time to indicate that the patient is now waiting for the completion of the patient record prior to discharge from the department. In the meantime the nurse responsible for the patient performs any nursing tasks in relation to the patient. This includes having bio-analysts take different samples from the patient or having any radiology tasks performed. If a bio-analyst has been called this is also indicated on the whiteboard by updating the Lab field. When the samples have been taken, the bio-analyst updates the Lab field to reflect this. During this time either the triage nurse or the attending nurse performs the secondary triage.

The physician and nurse assigned to the patient decide whether to transfer the patient to another ward or discharge the patient. If the patient is to be hospitalised the clinicians must decide what ward to transfer the patient to and notify this ward. Notification of the transfer has to be given at two levels: to a nurse at the receiving department and to a physician at the receiving department. The Transfer field is updated to show who has been notified at each of the two levels. Also, the Ward field is updated to show to which ward the patient is to be transferred. When the patient is ready to be transferred a hospital porter is called. This is indicted by updating the Porter field to reflect that a porter has been called. The Porter field also serves the purpose of giving the clinicians an estimated time of departure from the ED, since the clinicians know that it takes approximately five minutes for a porter to arrive and retrieve the patient. This is important for the logistic administration of the ED. When the patient is physically moved out of the ED the patient entry on the whiteboard is removed, while the information is kept in a database of the ED patients.

6 Implementation of the Electronic Whiteboards

In the spring of 2009 both EDs were invited to participate in the *Clinical Overview* project. In the summer of 2009 the project entered a planning phase where a large amount of time was spent discussing what information the system should display, what other clinical IT systems it should be interfaced with, and similar topics. The configuration of the system was based on the results from the planning phase and was done in close cooperation with the IT vendor Imatis. The system was ready to be used in the winter of 2009/2010 and was effectively taken into use in December of 2009 at ED1 and January of 2010 at ED2.

Both EDs decided to follow an experimental approach to implementing the electronic whiteboard system. This has meant that the system was implemented in an early version to allow the clinicians to use the system and gain experience with the system. Based on their experience with the system the clinicians have continuously provided the implementation group with feedback leading to iterative revisions of the system, its configuration and the associated work practices. As a starting point both EDs decided to configure the system layout to resemble the old dry-erase whiteboards. This was done to ensure that the system could easily be taken into use by the clinicians and fit relatively well into their normal work practices. To prepare the clinicians for the arrival of the new system different paper documents were prepared and on-site training was also provided. At ED1 the chief physician involved in the project had written a description of the system's information content, detailing what information the different columns display and the importance of this information. The chief physician was also present during the first week of usage to provide support in case the other clinicians needed assistance in using the system. Otherwise no training was provided in this case. At ED2 the system was introduced to the clinicians on the daily morning meetings. During these sessions the system's functions were demonstrated and the clinicians were able to see how the ED management intended the system to be used. Also, an instructional guide was written, detailing how the system was to be used and how the new work practices regarding the whiteboard were to be. At ED2 on-site support was also provided during the first week of usage and the daily shifts were carefully planned to ensure that there was always a clinician present who was familiar with the system.

The main difference between the implementation processes at the two EDs was that the management at ED1 made the adoption and usage of the new system voluntary whilst the management at ED2 made the usage of the system mandatory. At ED1 the rationale was that when the clinicians knew of the intended use of the new system they would by themselves explore the opportunities as long as they had the possibility of returning to the dry-erase whiteboards, which remained available. The clinicians could at any time choose to use one system or the other. At ED2 the rationale was that an immediate and definitive shift from dry-erase to electronic whiteboards was needed in order for the clinicians to adjust to the new system and work practices. Colleagues more experienced with the use of the system supported the clinicians in this shift. While ED1 and ED2 organised the implementation process of their electronic whiteboards differently in this respect, the end result has in both EDs been widespread and consistent use of the electronic whiteboards.

7 Balancing Tradition and Transcendence

As mentioned previously in this paper, the implementation of the electronic whiteboards at the two EDs was a balancing act of respecting the traditions of the existing work practices and at the same time progressing or transcending these practices by providing new possibilities to the work routines. One of the clearest examples of respect for the existing work practices is seen in the interface design of the electronic whiteboard where the matrix-like information structure was copied from the dry-erase whiteboards. Also, the intended use of the electronic whiteboards was envisioned to follow the existing work procedures in some aspects whilst transcending the existing practices in others. An example of how the use of the electronic whiteboards followed the traditional working practices was seen in how patient information was updated on the electronic whiteboard. With the dry-erase whiteboards, this was the responsibility of whoever had the needed information. This tradition has been carried over to the new electronic whiteboard system with the slight alteration of being able to update information in a distributed manner.

The distributed access also provided the possibility of transcending the existing work practices. An example of this was seen in the way the procedure regarding registration of new patients was changed during the implementation process. As described shortly in section 6, an instructional guide to using the system and the work procedures for this use was formulated as part of the implementation process at ED2. This guide details a generic patient trajectory similar to the one described in section 5 and also details who has responsibility for updating the electronic whiteboard at any given step in the treatment process. In the original version of the guide the medical secretaries were charged with the responsibility of registering new patients in the system. With the dry-erase whiteboards this was previously the shared responsibility of the chief physician (receiving the initial patient information) and the triage nurse (entering the patient information on the whiteboard) and thusly, the new instructional guide can be seen as an attempt to transcend the existing working practices. However, it quickly became clear that the new electronic whiteboards provided opportunity for an even more extensive change to this practice due to its possibility of distributed access. Thereby, the chief physician could, upon receiving the initial patient information, enter the information directly into the electronic whiteboard system and thereby save time and minimize the risk of errors or delays.

Other changes to the clinicians work practices were also made possible due to the system's option of distributed access. An example of this was seen at ED2, were the clinicians conduct so-called *time-outs* three times during a shift to discuss the patients currently at the ED. Before the electronic whiteboards were introduced the clinicians would hold these time-outs in front of the dry-erase whiteboards using them as a shared point of focus in the discussion of the patients. This was problematic since the whiteboards were placed in the ED control room and discussions regarding patients could potentially interfere with work in the control room. However, after the implementation of the new system it has been possible to move these meetings to another room with more space and seating options and more importantly away from the control room. This has only been possible because the system allows access from all devices with access to the central server. In the lens of balancing tradition and transcendence this is an example of how the existing working practices (holding time-outs) has been improved or transcended due to the possibilities that the new electronic whiteboard system provides.

Besides changes to the working practices of the EDs, there were also made changes to the system itself after its initial implementation. As described in section 5, the electronic whiteboard system contains a field displaying how long a patient has waited for the next step in the treatment process. This was not possible with the dry-erase whiteboards and this feature can therefore be seen as an attempt to transcend the existing practices. However, the initial design of the electronic whiteboards only supported the steps up to the point in the treatment process where the patient is awaiting the attending physician. Recognizing the advantages of being able see how much time is spent on the different steps, the physicians expressed a desire of being able to see how much time they spent on attending patients. Because of the system's possibility of easy reconfiguration this option was added to the list of steps in the Awaiting field and further transcended the work practices of the ED.

As described above the system provided different possibilities of transcending the existing working practices of the EDs. However, some features of the electronic whiteboard system, intended to improve the working practices, were experienced to be too extreme in the sense of respecting the existing working practices and therefore caused breakdowns in the working practice. This was especially seen in the system's patient-centred approach to administering the ED patients. In practice this approach creates a matrix of patient information that expands and retracts vertically when patients are hospitalised or discharged from the ED. This creates a very dynamic display of information since there is a constant flow of patients through the EDs and thusly, this display is very efficient for keeping an overview of the number of patients currently present at the ED. However, it is not efficient for keeping an overview of the number of vacant rooms since these are not shown on the electronic whiteboard. At the two EDs we saw that different types of workarounds were initially employed in order to compensate for this e.g. manually counting how many rooms are occupied or using the old dry-erase whiteboard as a supporting tool. These problems were reported to the implementation group as feedback and following the iterative nature of the implementation project, changes to the system were made in order to provide support for an overview of vacant rooms e.g. static rows for each room in the matrix information structure. Thereby, the system returned to supporting the traditional working practices. However, following this return to the traditional working practices it has become apparent that the attempt to transcend this practice, via the patient-centred approach to administering patients at the EDs, was valid in terms of the improving working practice – at least over time. This became apparent when the clinicians at ED2 later on requested that the system should be reconfigured (back) again to only show the occupied rooms and thereby transcend the working practices associated with administering the ED patients.

Another example of how the system did not fully respect the traditions of the EDs was found at ED1. Due to ED1's organisational structure it is necessary to divide the patients according to what type of physician their treatment requires. With the dry-erase whiteboards, this was previously done by writing the patient information with different colours. However, this has been down prioritized in the design of the electronic whiteboards, and this information is only visible in a single cell of a patient row placed too far to the right to be noticed by the clinicians and named in a manner that does not correspond to its intended purpose. A reason for configuring the electronic whiteboard in such a manner could be a preparation for the future organization of ED1, since this department is supposed to be organized in the same way as ED2, thereby removing the need to differentiate patients. However, this need will not cease to exist in the nearest future and therefore the clinicians have had to devise a workaround to compensate for the systems lack of respect for the current tradition.

8 Discussion

As described in the previous section, a number of changes to the working practices of the EDs followed as a result of implementing the electronic whiteboards. Some of the changes were anticipated and purposefully introduced. Others simply emerged and evolved as a result of using the system. As the analysis of the examples in the previous section shows, some of the changes respected the traditions of the working practices whilst others attempted to transcend these practices. Also, the analysis shows that it was not only the changes that respected the traditions that went on to be successful changes. In other words, some changes successfully transcended the existing traditions and became part of new work practices.

The difference between the changes that succeeded and the ones that were rejected can be related to the manner in which they were introduced. Some changes were initiated by the clinicians after they had experienced the system while others were introduced as part of a planned change in work organization needed to use the new system. The analysis shows that most of the changes initiated by the clinicians went on to become successful. A planned change introduced with the system (the patient-centred approach) was first rejected but later accepted – after the clinician's were allowed to experience both alternatives (representing tradition and transcendence, respectively).

This leads us to suggest that a viable strategy for balancing tradition and transcendence is using an implementation approach where the users of the system are allowed to work with it, develop their working practices, and make alterations to the system and work organization as they gain experience using the system. Such a strategy is very similar to the improvisational change management approach introduced by Orlikowski and Hofman (1997). In line with Orlikowski and Hofman (1997), many of the changes to the EDs work practices and the electronic whiteboards described, could be categorized as changes similar to the concepts of opportunity-based and emergent changes. For example, the change to the available choices in the system's Awaiting field can be seen as opportunity-based change since the system's functionality provided the clinicians with an opportunity to improve their work practice. Another example is the emerging change that evolved from using the electronic whiteboards when reconfiguring the work practice regarding registering new patients. This change was made possible by the distributed access to the system but was not actively planned or anticipated.Instead it emerged over a short period of time using the system and became a part of the working practices.

We believe that an improvisational implementation approach is a viable strategy when implementing IT systems in safety-critical settings such as the ED involved in our study. Such an approach strives to let the users of the system influence the configuration of the system and the associated work practices. The implementation at both EDs have resulted in a widespread acceptance and use of the electronic whiteboards. It is important to note that this result has been achieved through an on-going iterative process in which the implementation group continued to work throughout the implementation project. Based on continuous user feedback the implementation group has taken the action to alter the work practices and the configuration of the electronic whiteboards throughout an implementation period spanning several months.

9 Conclusion

The findings reported here illustrate that it is possible to implement new IT systems in safety-critical settings and at the same time improve work practices without imposing radical change or causing critical breakdowns. This can be achieved if the intended users are allowed to work with early versions of the system, gain experience with the system and provide feedback to an implementation group that is willing to receive the users' response and rapidly incorporate it into new versions of the system.

A way of balancing tradition and transcendence when implementing a new IT system is by following an implementation approach that allows changes to evolve based on the users' experiences from using the system. Changes might be a result of new possibilities supported by the system and/or a result of effectively balancing old practices with the new opportunities provided by the system. The implementation strategy introduced by the implementation group was a deliberate on-going and iterative one of changing procedures and practices one small step at a time. Thus far, the result of this strategy has been a successful implementation of the new electronic whiteboards keeping the well-liked practices while gradually gaining the benefits of the new system without compromising safety-critical issues.

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9.7 **Paper VII:** User participation in implementation

Declaration of co-authorship (PhD thesis)

Under Section 12 (4) of the *PhD order**, a declaration on the extent and nature of the relative contributions, signed by the collaborators and the author, must accompany the PhD thesis if the dissertation or parts of it are the result of collaboration.

Co-authors should fulfil the requirements of the Vancouver rules**

1. General information	
Name of candidate	Rasmus Rasmussen
Title of PhD thesis	Electronic Whiteboards in Emergency Medicine: Studies of implementation processes and user interface design evaluations

2. This co-author's declaration applies to the following article/manuscript No.
Fleron, B., Rasmussen, R., Simonsen, J. and Hertzum, M., 2012. User participation in implementation. In: Proceedings of the Participatory Design Conference, ACM, New York, NY, USA, pp. 61-64.

The extent of the candidate's contribution to the article is assessed on the following scale:

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1. Formulation in the concept phase of the basic scientific problem on the basis of theoretical questions, which require clarification, including a summary of the general questions, which it is assumed, will be answered via analyses or actual experiments/investigations.	B
2. Planning of experiments/analyses and formulation of investigative methodology in such a way that the questions asked under (1) can be expected to be answered, including choice of method and independent methodological development.	B
Involvement in the analysis or the actual experiments/investigation.	B
Presentation, interpretation and discussion of the results obtained in the form of an article or manuscript.	B

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Date	Name	Title	Signature
24.01.2013	Benedicte Fleron	PhD fellow	[signature]
24/1-2013	Jesper Simonsen	Professor	[signature]
24/01-2013	Morten Hertzum	Associate professor	[signature]

5. Candidate's signature
Rasmus Rasmussen

The declaration of co-authorship should be submitted with the PhD thesis to the Doctoral School.

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User Participation in Implementation

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ABSTRACT
Systems development has been claimed to benefit from user participation, yet user participation in implementation activities may be more common and is a growing focus of participatory-design work. We investigate the effect of the extensive user participation in the implementation of a clinical system by empirically analyzing how management, participating staff, and non-participating staff view the implementation process with respect to areas that have previously been linked to user participation such as system quality, emergent interactions, and psychological buy-in. The participating staff experienced more uncertainty and frustration than management and non-participating staff, especially concerning how to run an implementation process and how to understand and utilize the configuration possibilities of the system. This suggests that user participation in implementation introduces a need for new competences. Our results also emphasize the importance of access to fellow colleagues with relevant experience in implementing systems.

Author Keywords
User participation, Organizational implementation

ACM Classification Keywords
K.6.1 [Management of computing and information systems] Project and People Management

INTRODUCTION

User participation in the development and implementation of information technologies (IT) has been claimed to result in three overall effects on system success (Markus & Mao, 2004): (1) An improvement of the quality of the system, (2) emergent interactions and "good" relationships between designers and users, and (3) a psychological buy-in regarding the user's acceptance of the system. As participatory design (PD) becomes an increasingly popular approach to both developing and implementing IT systems (Simonsen & Robertson, 2012) it simultaneously becomes interesting to explore the role, competencies, and needs of users' participation in the implementation of IT. Dittrich et al. (2002) avoid a distinction between development and implementation by instead extending design to also include design in use. They propose that design in use, which resembles how we talk about implementation, comes with its own challenges, which, for example, include how to support design-in-use activities organizationally.

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We have investigated the result of the user participation in the processes of designing and, especially, implementing an electronic whiteboard at Danish emergency departments (EDs). This process was perceived differently depending on which group of clinical staff we interviewed and which role they had in the process. We relate our findings to the arguments for user participation given by Markus and Mao (2004) but here applied to an implementation context. In relation to Dittrich et al.'s (2002) concerns we describe what went wrong and right in this process from the perspectives of management, the clinical staff participating in the implementation process, and the clinical staff who did not participate in the process but were merely informed about the system and expected to use it. Our results extend the understanding of applying a PD approach from design to an implementation process in which the users are in charge of the installation, configuration, and organizational implementation of IT. We emphasize the role of the participating staff, their needed skills and competences and the organizational support therein.

CASE DESCRIPTION

We report from a case study of an IT project initiated by the Danish healthcare region of Zealand and carried out in collaboration with Norwegian IT vendor Imatis and Roskilde University. The goal of the project was to design and implement an electronic whiteboard as a replacement for the dry-erase whiteboards previously used in coordinating patient care and clinicians' work in the healthcare region's four EDs. The project was carried out in two main phases. The first phase, completed in early 2011, aimed at designing and pilot implementing the electronic whiteboard at two of the four EDs (ED1 and ED2). In this phase selected clinicians participated as clinical advisors and co-designers of the electronic whiteboard's functionality and user interface. The work in the first phase was driven by a project group consisting of these clinicians together with representatives from the healthcare region and the IT vendor, see Rasmussen et al. (2010).

In this paper we focus on the second phase of the project in which the latest version of the electronic whiteboard was implemented at the two remaining EDs (ED3 and ED4). At this point the system was in a state where it could be implemented and used without needing further development, except local configuration. In an attempt to ensure a proper fit between the electronic whiteboard and the EDs the responsibility of configuring and implementing the system was assigned to the individual EDs. In practice, a few clinicians at each ED were responsible for the local implementation of the system.

ED3 and ED4 are located at two larger hospitals in Region Zealand and provide a single point of entry to the hospitals for all acute patients. This includes patients who are brought to hospital by ambulance, walk-in patients and patients referred to the hospital by their general practitioner. ED3 employs 35 nurses and 25 full-time physicians and has 10 patient rooms. ED4 employs a total of 120 nurses and 13 full-time physicians. In addition, it allocates physicians from other departments on an on-call basis. ED4 and has 21 patient rooms.

EMPIRICAL APPROACH

We conducted 17 semi-structured interviews with three clinicians directly participating in the implementation process (one from ED3 and two from ED4), ten clinicians not participating in this process (five from each ED), and four managers (two from each ED). The interviews were loosely structured, audio-recorded, and lasted 0.5 - 1.5 hours. We made unique interview guides for each of the three groups of interviewees.

In analyzing the interviews we first perused and coded the notes taken during the interviews. This provided an initial set of coding categories, which we used in the following coding of the audio recordings. Each recording was coded using a grounded theory (Strauss and Corbin, 1998) inspired approach, meaning that we constructed coding categories on the basis of the recorded material as well as our notes. We were especially aware of descriptions of how the clinicians had been involved in the implementation process, how they had fulfilled this role, their satisfaction with the electronic whiteboards, whom they felt had been responsible for the implementation process, and how the process had been organized in general. The resulting set of categories was applied recursively to the audio recordings using Nvivo9™ to ensure that all relevant statements had been found. The final coding was discussed amongst the authors, and statements that were especially exemplary were selected and transcribed for use as examples in this text.

QUALITY OF THE SYSTEM

Markus and Mao's (2004) system quality explanation basically argues that user participation provides designers with an improved understanding of the system requirements, and this is expected to result in higher system quality. They further note, as a 'gap' in this explanation, that research gives ample evidence that high-quality requirements produced via user participation does not necessarily mean that these requirements are borne out in a high-quality design of the system itself.

In our implementation context an equivalent explanation would be that user participation should provide an improved understanding of the organizational implementation process expected to result in a high-quality system configuration and organizational implementation. An equivalent gap would be that the result of the implementation to a lesser extent met the technical and organizational change potential.

Our interviews show that while the management and non-participating staff at the two EDs experienced a rather successful implementation, those who were locally responsible for the implementation process – the participating staff – experienced a chaotic and challenging task.

Management

The management's view at both EDs was that of a smooth and easy implementation – *"I've never been part of anything that easy to implement, I really haven't."* (Mgmt, ED4). This refers to the ease with which the staff adopted the system and took it into daily use, which management expresses was due to the simple and intuitive design of the electronic whiteboards. *"...It's so user-friendly that you can almost figure it out by yourself"* (Mgmt, ED4). The user-friendly design along with the utility of the system was the reasons for its smooth implementation, even though some skepticism existed prior to the arrival of the whiteboards. *"If you have to implement something that your staff thinks is wide off the mark, then it's difficult to implement. In this case, however, everyone could see right away that this helps us in our daily work with the patients – and then it's easy to implement"* (Mgmt, ED3).

At ED3 the main managerial issues concerning the process of implementing the electronic whiteboards involved a lack of resources, coordination, and management support from the project group. They were especially referring to a lack of IT know-how, which was evident in the process of configuring the whiteboards and making the system function on the computer in the patient rooms. Though the local coordinator had some personal knowledge and interest in IT, it was not his main work area, and the person who helped them the most was from ED1 and had to divide his time between his engagement in his support of ED3 and ED4, and his daily work at his own ward, ED1. *"Maybe we should have had an extra IT supporter, instead of the load lying heavily on one and a half man's shoulders"* (Mgmt, ED3).

Participating staff

The participating staff involved a few key clinicians who were locally appointed as being coordinators responsible for system configuration and organizational implementation. They have collectively described the implementation process as one where no one knew who was responsible for what, along with a feeling of not really knowing what it entitled to be locally responsible for such a process. So for this user group a link between successful implementation and the participation of designers seems important.

Though the implementation process was initiated differently at ED3 and ED4, the participating staff had similar experiences of the process with all its practicalities. At both EDs they voiced an absence of proper information and communication from the project group to the local coordinators, who felt unprepared for handling the task of implementing the whiteboards. At ED3 the local coordinator experienced the whole process as *"... something, which kind of crept up on us. We vaguely heard here and there that something was on its way and then there was a meeting where some were invited and others weren't, and then we were suddenly in the middle of it. Though, we had not even had time to organize. And, nobody had really taken responsibility for it"* (Participant, ED3). This local coordinator was informed quite late in the process and, therefore, did not attend the mentioned meeting, at which the electronic whiteboards and their introduction at the ED were initially described, discussed, and related to the overall project. The experience of the participating staff at ED4 differed from that of ED3 because they took part from the beginning. Hence, they did not feel side-tracked, though it was unclear to them who were responsible for the different tasks related to the implementation. *"It was, for a long time, very unclear who actually should get the ball rolling and get IT [i.e. the IT department] going because they were apparently not part of the project"* (Participant, ED4).

Non-participating staff

Contrary to the statements from the participating staff at ED3 the non-participating staff had a good experience of the process and mentions a satisfying information flow prior to taking the system into use. Members of all staff groups mention being informed about the upcoming electronic whiteboards at several morning meetings or conferences as well as having received emails on the subject. At ED4 the non-participating staff had a more diverse experience of what happened prior to the introduction of the whiteboards. Some of the staff expressed no recollection of having been informed or having received any introduction prior to when they had to start using the electronic whiteboards. *"Not much, I think. I can't remember it. I only remember that we went down to the secretaries' office…, and then we could draw on one of the participating staff who could tell us a bit"* (Non-participant, ED4). Some of the staff mentioned an introduction day facilitated by the participating staff and an email with the date for the setup of the screens.

Discussion

Management unanimously experienced the implementation process as successful. Due to a lot of other obligations they did not engage much in the local implementation process, which they delegated to the participating staff. Also, management had no specific competence in managing IT implementation processes and as their colleagues from ED1 and ED2 had demonstrated the quality and usability of the system it seemed unintimidating to the staff because it did not introduce drastic changes to the daily work practices. But the participating staff experienced a lack of organization, structure, and management. From their point of view the process was chaotic and problematic.

The challenges experienced by the participating staff resulted in a limited system configuration and, thereby, in a system supporting a modest level of potential change. Their struggle in managing the many practical implementation issues did not leave much incentive for extensive technical configurations or innovative experiments with new ways of organizing work.

EMERGENT INTERACTIONS AND BUY-IN

According to Markus and Mao (2004) user participation fosters emergent interactions that give rise to "good" relationships between designers and users. During the design phase active participation also fosters a positive attitude toward the new system, which often makes participants feel committed and inclined to adopt and use the system. This positive attitude and desire to use is known as psychological buy-in. Emergent interactions result in relevant requirement information and designers who can incorporate these requirements in the system (Markus and Mao, 2004). However, *"the emergent interactions explanation […] cannot bridge the gap between participation's role in the development of a system and its effects on system acceptance and use"* (Markus and Mao, 2004, p. 521). In addition, the users who do not participate directly do not have the same incentive to buy in to the system – in our case all users appeared to do so. The designer-user relation was, however, perplexing and included relations among multiple roles and stakeholders.

Management

At both EDs, neither management nor the non-participating users participated directly in the implementation process. At a managerial level ED3 experienced that too much was left for themselves to figure out with no guidelines, introduction, or information from the project group. This increased their dependence on their contact to ED1. In addition, they experienced some political bureaucracy, which for example resulted in a 14-day delay of taking the system into use. The regional IT security department decided that the electronic whiteboards could not be used until they had inspected them and ensured that the setup conformed to the hospital's privacy legislation.

Participating Staff

The participating staff at both EDs acknowledged the crucial importance of the personal help and engagement from some of the individuals in the project group. At ED3 they received tremendous help and assistance from the participating staff from ED1. *"My hat's off to him. If we call and tell that we're desperate then two hours later he's here – in spite of him also being the managing nurse at [ED1]. So it's not that we haven't had support if we needed it. We just didn't have that focus ourselves"* (Participant, ED3). ED3 was, however, disappointed with the lack of project management assistance from the Region. In contrast, ED4 received helpful and appreciated support from the Region's project manager during the implementation process. *"I was glad that the project manager was there, because the screen was a bit of a hassle. Had it not been for her then we would just have been standing there…and euhm fish. But then she could contact Norway [i.e. the IT vendor] to get things fixed, so we used her numerous times"* (Participant, ED4).

Non-participating Staff

The non-participating staff at both EDs expressed a wish for an earlier introduction and training in using the new whiteboards as well as a possibility for trying out the whiteboards before they went into daily use. They also missed a coordinated and collective introduction to the system instead of being introduced to it in an ad hoc manner by a colleague when they first encountered the system. Thus, their buy-in cannot be based on any first-hand experience or close relation to other participating stakeholders. Instead, they might have based their assessment of the system quality on reputed credibility (Tseng and Fogg, 1999) because it was developed and well-liked by their colleagues at ED1 and ED2. The non-participating staff did not resist the system, and the participating staff gradually took ownership of it in spite of the challenges they faced: *"We have been hesitating in taking ownership, so we have also only very slowly reaped the possible benefits of the screen… Implementation-wise we should have assumed responsibility much earlier, but we didn't. There're several reasons for that but essentially I think it was because we didn't understand what we had started"* (Participant, ED3). We interpret the transfer of psychological buy-in from their colleagues at ED1 and ED2 as crucial to the largely positive adoption of the system at ED3 in spite of the participating staff's initial hesitation. In addition, ED1's participating staff played a significant supporting role in the implementation at ED3.

Discussion

The experiences uttered by all three user groups in our case point to the importance of having engaged and involved participation by designers during both development and implementation. The term 'designer' in our case includes the roles of project management, local IT security, configuration, and peers engaged in facilitation and knowledge sharing – especially the participating staff who took part in the process at ED1 and ED2. The role of the participating staff resembles what Dittrich et al. (2002, p. 130) term shop floor IT management, that is "*the everyday work of making IT work*". The role of the participating staff was intricately interwoven with use and shows how the implementation and local adoption of the system evolved as a process of design in use.

CONCLUSION

We have analyzed how the effects of user participation traditionally associated with IT design relate to user participation in the implementation of a clinical system.

The main implication of our case concerns the role of the participating staff, which has previously been characterized as shop floor IT management. To fulfill this role the participating staff need new skills as well as resources and support from their management. In our case the support needed was mostly provided by the project group, which suggests a strong link between their participation and the largely successful implementation process. The help and guidance from their colleague who had been central to the implementation of the electronic whiteboard at ED1 was particularly important to the participating staff's ability to manage the implementation process. This indicates a need for support in the process of envisioning how a new system can support improved ways of working and a need for new skills, unrelated to their clinical profession. The areas in which the participating staff at ED3 and ED4 needed support and new skills included:

- Deciding on the number and location of the electronic whiteboards, and figuring out the need for additional hardware such as keyboards and login devices.
- Collaborating with the local IT department.
- Learning the configuration possibilities of the electronic whiteboards and using them to adapt the whiteboard to local needs and practices.
- Introducing their colleagues to the electronic whiteboards and assuming a role of system champion to overcome barriers and uncertainties.
- Adjusting procedures and transferring these procedures into their colleagues' daily work practices to capture the benefits provided by the electronic whiteboards.

The new role and skills required from the managerial level would in our case be to allocate resources to and support the establishment of a network among the participating staff at the four EDs. Such a peer-to-peer network could have supported the participating staff at ED3 and ED4 in understanding and fulfilling their role. A central benefit of such a network would be as an official and acknowledged forum for exchanging experiences, collaboratively finding solutions, and otherwise helping and guiding each other. This could also help foster a base for "shop floor IT management" (Dittrich, Eriksén & Hansson, 2002) in the further development of the electronic whiteboards when they are transferred and adapted to the other departments at the Region's hospitals, throughout which they are gradually to be implemented.

What we take with us from this study is the knowledge that PD in implementation is about providing resources to support a peer-to-peer network among the designers with whom the users form emergent interactions. This network should, in our case, include the project group members, the regional project manager, the participating staff from the EDs, developers from the IT vendor, and the local IT department. The purpose of the network is to help the individual participating clinician in acquiring the skills needed in performing their role as clinical shop floor IT managers.

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