Evaluating the Usability of a Mobile Collaborative System: Exploring Two Different Laboratory Approaches

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ABSTRACT
Several years of research in industry and academia has shown that usability issues influence users' interactions and perceptions of the software products. High usability may prove critical in the success and survival of a product. The diffusion of new advanced technologies seems to challenge established ways of conducting usability evaluations. E.g. several mobile collaborative systems are difficult to evaluate in their natural inhabitant since the use situation is very complex involving distributed work tasks and actions while other mobile collaborative systems deal with safety-critical issues involving risks for people and equipment.

This paper describes an exploratory study of two different approaches to usability evaluation of the same mobile collaborative system for coordinating work tasks on a large container ship. The two evaluations are based on an expert evaluation (heuristic inspection) and a user-based evaluation (usability testing with the think-aloud protocol). The two evaluations were conducted in laboratory settings in order to identify potential strengths and weaknesses of the different approaches. The primary result of the study is that from the heuristic inspection it is difficult to identify usability problems related to the support for collaborative work. The reason for this is that heuristic inspection is conducted centralized. The problems identified in the heuristic inspection more concern general interaction issues. In the think-aloud evaluation on the other hand, a large number of collaboration related usability problems were revealed.

KEY WORDS
Mobile collaborative systems, safety-critical, usability, think-aloud, heuristics

1. INTRODUCTION
Many years of research have shown that aspects of usability are important to investigate and address during software design and implementation, cf. (Rubin 1994). Usability of software have shown to influence user mistakes and satisfaction, and system performance (Molich 2000). Furthermore, lack of usability affects loyalty of users and leads to employee dissatisfaction and high staff turnover (Hodgson and Ruth 1985). With the introduction of the web, usability has become a decisive competitive factor to consider (Nielsen 2000).

Emerging software systems and technologies challenge our established approaches to design and evaluation. These approaches are mainly built upon experiences from designing and evaluating traditional systems (Molich 2000), e.g. desktop applications for supporting work tasks (like a word processor). However, new technologies do not necessarily share all the same characteristics as traditional technologies. E.g. the Internet and World Wide Web integrate web information systems that are highly differentiated, attract very different kinds of users, and pursue different goals (Spool 1999). The diverse use purposes and the indefinable use contexts and situations makes usability complex for many web information systems, cf. (Badre 2002, Krug 2000, Nielsen 2000).

Mobile collaborative systems constitute an emerging class of software systems and technologies that have penetrated diverse environments during the last couple of years. This diffusion has primarily been made possible due to the introduction of hand-held devices such as PalmPilot™ and PocketPC™ based PDAs. Luff and Heath (1998) e.g. outline the necessity for mobility in collaboration in various settings such as health consultations, construction sites, and public transportation. Like in the mobile collaborative systems described in Rist et al. (2000), the focus is on the need for information and mobility in different specific contexts. However, mobility and collaboration raise a number of potential problems related to testing the usability in the field (Nielsen 1998). First, it is difficult to study certain mobile collaborative systems in the field e.g. since the use of the system is temporally and spatially distributed among several actors and furthermore these actors move around while using it. This complicates setting up a realistic and controllable usability evaluation. Secondly, some mobile collaborative systems (c.f. Nielsen and Søndergaard 2000, van den Anker and Lichtveld 2000) deal with safety-critical issues involving risks for people and equipment. This further prohibits exploratory evaluations of the system since mistakes cannot be tolerated. Summarized, we need to explore how well evaluations of mobile collaborative systems can be conducted in laboratory settings.

Fundamentally, approaches to usability evaluations may be either expert, theoretical, or user-based (Henderson et al. 1995) or a combination of these (Cuomo 1994). Many of the established strategies for usability evaluation involve, however, user-based components. The differences between heuristic inspections and user-based usability testing have been shown for standard desktop applications (cf. Karat et al. 1992), and for web-sites, (cf. Kantner and Rosenbaum 1997). One of the identified key characteristics is that user-based usability testing tends to find more usability problems than heuristic inspection and that the problems found are usually more relevant to end users. On the other hand, user-based usability testing is more time consuming than heuristic inspection, cf. (Molich and Nielsen 1992). Such issues still need to be explored for mobile collaborative systems.

This paper explores an expert-based evaluation approach and a user-based evaluation approach in the testing of a mobile collaborative system. Section 2 presents the background for the study outlining the involved case and describes the mobile collaborative system of focus. Section 3 outlines the method behind the study describing how the evaluations were set up and carried out. Section 3 highlights the key results of the study, and finally section 4 discusses the results and their potential implications.

2. BACKGROUND

In the following section, we describe the case applied in the study on mobile collaborative work. This case involves the collaborative task of operating of a large container vessel. Furthermore, the mobile system designed to support this task is illustrated and explained.

2.1 Mobile Collaboration: An Example Domain

The operation of container vessels in sizes equivalent of 3½ soccer fields require a large amount of collaboration among distributed mobile actors. Typically, the crew size is limited and crew members are assigned to various tasks at various locations on the ship depending on the present situation: cruising at sea, maneuvering through thick fog in trafficked waters, arriving at a harbor, departing from the quay etc.

The collaborative work tasks in the above setting are safety-critical and involve high risks in the case of errors. Especially when maneuvering inside a harbor, erroneous actions may result in the vessel running aground or colliding with the quay or nearby ships. In either case, such collisions would cause serious material damage, potentially severe injuries on personnel and possible loss of human life. Thus, the coordination of activities among distributed actors during these operations is significant.

For the purpose of supporting collaborative work tasks in the maritime domain, an experimental mobile device prototype was designed and implemented on the basis of ethnographic studies of cooperative work activities on a Maersk-Sealand container vessel during the operation of "letting go the mooring lines" (Nielsen 2000, Andersen and May, 2001, Kjeldskov and Stage 2002).

Figure 1. The aft mooring of Sally Maersk

When a ship is ready for departure, the first step in leaving the quay is letting go the mooring lines holding it in a fixed position (figure 1). As physical space is restricted and means for precise maneuvering are limited, all lines cannot simply be released simultaneously. When a line is let go, it will remain in the water for a period of time during which no means of propulsion is available due to the risk of lines getting sucked in and wrapped around the propeller or thrusters. Instead the vessel can be pulled ahead or astern by means of the remaining lines. Following these premises, lines are released sequentially in accordance to the specific need for maneuvering of a given situation.

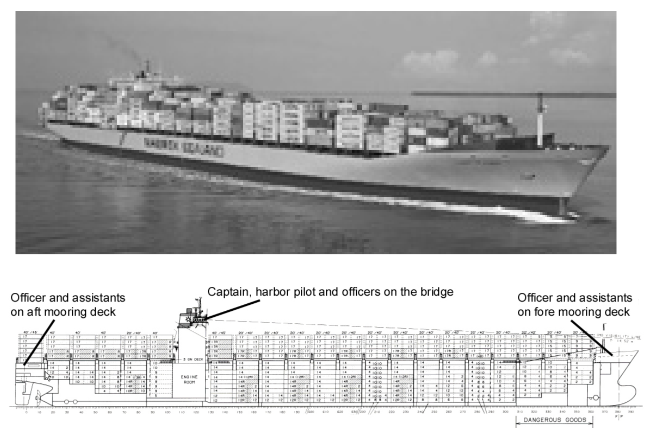

Figure 2. Sally Maersk - one of the world's largest container vessels in operation

Due to the huge size of container ships, the different work tasks involved when letting go the lines are distributed among a number of actors located at strategic positions (see figure 2). On the bridge, chief officers control the rudder, propeller and thrusters. Fore and aft, the first and second officers control the winches for heaving in the lines. Ashore, two teams of assistants lift the lines off the bollards. In the situation depicted in figure 3, for example, the challenge consists of bringing the vessel away from the quay sideways without running aground in the shallow water behind it or colliding with the ship at quay in front of it. Because of wind, current, temporal lack of propulsion and poor visual view from the bridge, this operation is not trivial but must be carefully coordinated.

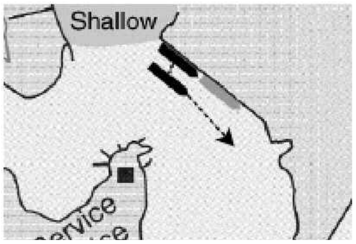

Figure 3. Strategy for departing from harbor

To insure the safety and successful completion of the operation, individual work tasks of letting go the lines are carried out under strict command of the captain in charge, relying on the feedback from personnel on deck. At present this coordination is primarily based on oral communication following well established formalized procedures. While people on the bridge can see and hear each other, personnel on deck are out of direct visual and audio contact and have to communicate with the captain via walkie-talkies. To verify that a command has been successfully received and understood, the receiver of a command is required to confirm it by repeating it. If no confirmation is received, the command will be reissued within a given window of time.

In order to carry out the operation of departure in a safe manner, the captain needs an overview and total control over the propulsion, direction and mooring of the ship. While information about the rudder, propeller and thrusters are available on dedicated instruments no information about mooring is facilitated. At present this only exists as a mental model in the head of the captain based on his perception of the ongoing communication between bridge and deck. As this mental model is highly sensitive to errors or misunderstandings in the communication, and since disparity between the captain's mental model and the real world may cause wrong decisions, considerable cognitive resources are spend on establishing and maintaining common ground (Clark and Schaefer, 1989) among the cooperating actors.

2.2 Coordination of the Collaborative Work Task

From an activity theoretic perspective (Engeström 1999, Bardram 1998), cooperative work can be coordinated either scripted, communicatively or instrumental.

In *scripted* coordination of cooperative work, involved actors follow a mutual formal or informal plan for the completion of a joint work task. Thus all actors are aware of the distribution of work and the sequence of actions to be taken. In *communicatively* coordinated cooperative work, the completion of the joint work task is negotiated among the involved actors by different means of communication, orally or text based, direct or mediated, synchronously or asynchronously. Finally, coordinating cooperative work *instrumentally,* the involved actors react on the action taken by others, and adapt their own actions correspondingly for the realization of a common goal.

In practice, these mechanisms seldom exist in pure form. Instrumental coordination may very often rely on an underlying mutual plan or script, which may be modified through communication. In the same way, communicative coordination often results in the creation of formal or informal plans or routines.

In the operation of letting go the lines, all three mechanisms for coordination are involved. While the specific sequence of work tasks is primarily coordinated communicatively (nothing is done without reporting it to the other actors involved), this sequence is based on an overall script of actions, in which some steps naturally precede others. Furthermore, instrumental coordination is prevalent as actions taken by one actor are often highly visible to the others. For example, personnel on the quay will typically pull the specific lines off the bollards that are made slack by the assistants controlling the winches.

2.3 Limitations in Present Means for Coordination

From our ethnographic studies, a series of limitations in present means for coordinating the collaborative work tasks on board the container vessel was identified.

Sound quality of radio-transmitted communication is often poor and multiple parallel tracks of conversations result in bottlenecks and high cognitive load. Furthermore, spoken communication is not persistent and vital information thus has to be remembered. Scripted coordination is often constrained by the lack of explicit representations of plans as well as ad-hoc changes being made by the captain. Finally, instrumental coordination suffers from relevant processes or activities being visually obscured due to large physical distribution of actors or poor visibility due to bad weather conditions.

As asynchronous text-based messaging is a flexible, ubiquitous and persistent communication channel requiring low cognitive overhead as discussed in e.g. Churchill and Bly (1999) and Popolov et al. (2000), it was the thesis of the development team that shifting to text-based communication on mobile devices could eliminate or reduce some of these limitations.

2.4 The Prototype Application

A prototype of the "Handheld Maritime Communicator" was designed and implemented for supporting the task of letting go the lines (Kjeldskov and Stage 2002). The prototype was targeted at a Compaq iPAQ 3630 handheld computer with 32MB RAM and a color display of 240x320 pixels running Microsoft PocketPC. The prototype setup consisted of two iPAQs and a PocketPC emulator running on a Fujitsu-Siemens B-2154 laptop computer. The reason for using a PocketPC emulator as the third device was merely a question of available hardware for the present study. As the laptop like the iPAQs was operated by means of a touch screen, interaction with the PocketPC emulator was very similar to interacting with the real device. The three devices were connected through an IEEE 802.11b 11Mbit wireless

TCP/IP network. One device was indented for the captain on the bridge while the other two were indented for 1st and 2nd officers on the fore and aft deck respectively. The prototype was implemented using Microsoft Embedded Visual Basic and the PocketPC SDK.

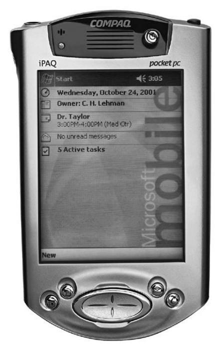

Figure 4. Compaq iPAQ handheld computer

The prototype supports the coordination of collaborative work tasks by facilitating a text-based communication channel and suggesting appropriate commands on the basis of a formalized description of the overall script of the operation. Representing the actions of the distributed actors graphically supports instrumental coordination.

The overall interface is divided into four sections (see also figure 5):

- Pictogram of the ship and mooring lines
- List of completed communication threads
- List of ongoing threads of communication
- List of unexecuted commands

At the bottom of the screen, unexecuted commands and confirmations are displayed on a list. The order of the list corresponds to the standard sequence of the overall operation and command only appears when appropriate. By default, the most likely next step of the operation is highlighted. The list can be browsed with the five-way key on the device, located immediately below the display, and the highlighted command is executed (send) when pressing the center of the key.

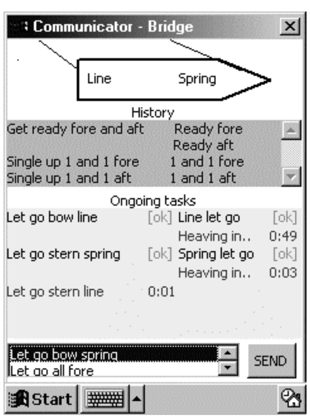

Figure 5. The interface on the bridge

The most important element of the interface is the list of ongoing tasks. In this list, all ongoing threads of communication are represented textually, grouped in accordance to the object, which they refer to. When a command is executed, it appears on the list of ongoing threads of communication Next to it, a counter displays the time passed while waiting for confirmation (figure 6a). When a command is confirmed, the timer is substituted by the text “[ok]” followed by a description of the current activity (e.g. “Singling up...”). A counter next to this displays the time passed since confirmation (figure 6b). When a task is reported completed, a short statement (e.g. “1 and 1 fore”) substitutes the description of activity and the captain is prompted for confirmation (figure 6c). When the completion of a task is confirmed, this is indicated by the text “[ok]” (figure 6d).

Figure 6. Commands being executed (a), confirmed (b), completed (c) and confirmed (d)

When the captain confirms the completion of a task, the corresponding thread of communication is removed from the list of ongoing tasks and added at the bottom of the history list. The history list is simplified by removing less relevant and implicit information such as timers and confirmations. When the history list is full, it automatically scrolls the oldest commands and statements out of immediate sight.

In top of the display, a simple graphical representation depicts the lines currently attached to the quay for quick reference. Additionally, the status of fore and aft mooring is shown textually. Simple sound cues direct attention towards the device when commands, confirmation and reports of completion appear.

3. METHOD

The idea of the study is to explore opportunities and limitations of two laboratory approaches to usability evaluation. The first subsection describes the setting and conduction of the expert evaluation while the second subsection outlines the setting and conduction of the user-based evaluation. Finally, subsection 3.3 presents the data analysis in both approaches.

3.1 Heuristic Inspection

In our first study, we applied an established method for expert evaluation developed by Molich and Nielsen (1990). The aim of this approach is to test the basic design of an interface using few resources and without involving users.

A team of three trained usability experts was given a 15-minute joint oral introduction to the use context of the prototype application supported by a number of illustrations on a whiteboard, drawn in advance (figure 7). The introduction covered the overall operation to be supported, the basic concepts and maritime notions involved, the distribution of work tasks and present procedures of communication and coordination (as described in section 2).

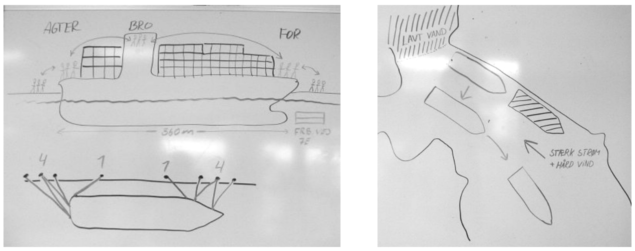

Figure 7. Introduction to use context on whiteboard

Aided by a standard heuristic for usability design (Dix et al. 1998:413) photocopied onto an A4 handout, each member of the expert team then spend one hour on checking for usability problems while using the prototype. Problems identified were noted on a laptop computer as they arose. The heuristic guiding the inspections consisted of the following issues for usability design:

1. Simple and natural dialog
2. Speak the user's language
3. Minimize user memory load
4. Be consistent
5. Provide feedback
6. Provide clearly marked exits
7. Provide shortcuts
8. Good error messages
9. Prevent errors

After the inspections, the expert team was given one hour of discussion during which a final list of problems should be produced. The team did not receive any instructions on how to use the prototype prior to the inspections.

Figure 8. Heuristic inspection

The inspection setup consisted of two Compaq iPAQs and a PocketPC simulator on a laptop PC connected through a wireless network. The PocketPCs displayed the interfaces for officers fore and aft respectively while the laptop displayed the interface for the captain on the bridge. Two A4 handouts depicted standard patterns of mooring and explained 10 basic concepts and notions of the maritime context for quick reference if necessary. In case of technical problems, an operator could be contacted in a nearby office.

3.2 Usability Testing with Think-Aloud

In our second study, we focused on the usability of the mobile prototype application as experienced by users without any knowledge of the maritime domain in a controlled environment. This study was conducted in a usability laboratory facilitating the observation of two physically separated simultaneous experimental setups. As depicted below, the laboratory consisted of three separated rooms: two subject rooms and a control room.

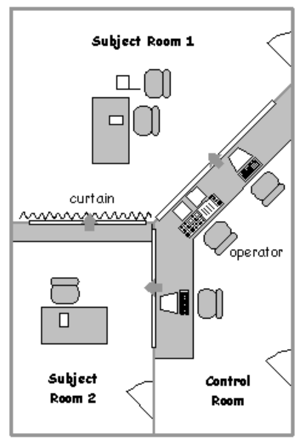

Figure 9. The layout of the usability laboratory

From the control room, both subject rooms could be surveyed by an operator through one-way mirrors and by means of motorized cameras mounted in the ceiling. From each subject room, it was not possible to look into the other. For our specific experiment, subject room 1 resembled the bridge of the ship while subject room 2 resembled the fore mooring deck.

Figure 10. The control room

Three teams of two test subjects, who were all students of Informatics at the Department of Computer Science at Aalborg University, were given the task of letting go the lines before departure of a large vessel, communicating exclusively by means of textual commands executed on their mobile devices. The test subjects received the same 15-minute joint oral introduction to the use context as given to the expert team. Following this, one person was asked to act as the captain on the bridge while the other acted as officer on the fore mooring deck. The reason for using a total of *six* persons in the think-aloud study compared to the use of only *three* expert evaluators was that unlike the expert evaluators, each user in the think-aloud evaluation only had access to a limited fraction of the total system. Thus in both the heuristic inspection and the think-aloud evaluation, three people interacted with the interface for the bridge the mooring deck respectively. Furthermore, previous research show that doubling the number of expert evaluators in a heuristics inspection from three to six would *not* result in the identification of a significantly higher number of usability problems (Molich 2000).

As the interface design for fore and aft mooring deck were identical, and because evaluating all three interfaces simultaneously would only complicate the laboratory setup further by requiring an additional subject room, test subject, evaluator etc., we decided not to include user-evaluation of the aft mooring deck in this study. Instead, this device was operated by one of the evaluators.

During the evaluation, the test subjects were asked to think-aloud, explaining their comprehension of and interaction with the prototype. An evaluator located in each test room observed the test subjects and frequently asked them about their actions. On a video monitor facing away from the test subjects, the evaluators could see a close up view of the test subject's mobile device as well as the activities in the other subject room for an overview of the evaluation.

Figure 11. Setup in subject room 1 (top) and 2 (bottom)

As in the heuristic inspection, the laboratory setup consisted of two Compaq iPAQs and a PocketPC emulator on a laptop PC connected through a wireless network. The two iPAQs displayed the interfaces for the officer on the fore mooring deck and the captain on the bridge respectively. The laptop displayed the interface for aft mooring deck and was used by one of the evaluators. For quick reference, the test subjects were provided with the same A4 handouts explaining standard patterns of mooring and notions of the context also given to the expert team.

The test subjects were seated at a desk with the mobile device located in front of them. In order to ensure that the video cameras could pick up a good image of displays, the test subjects were asked to keep the mobile devices within a delimited area, drawn on a white piece of paper taped to the desk (see figure 11).

Remotely controlled motorized video cameras mounted in the ceiling of usability laboratory captured high quality video images of the evaluations. Two cameras captured overall views of the test subjects while using the system and two cameras captured close up views of the mobile devices. The four video signals were merged into one composite signal and recorded on digital video (figure 12). Sound from the two test rooms was recorded on separate audio tracks for later mixing and potential separation during playback.

Figure 12. The digital video recording

3.3 Data Analysis

The data analysis aimed at creating two lists of usability problems identified in each of the two approaches. For the heuristic evaluation, this was pretty straightforward since the heuristic inspection directly resulted in a list of usability problems describing the problem categorized by the given nine heuristics.

The think-aloud evaluation, however, consisted of three video recordings depicturing the test sessions with the six test subjects and had to undergo further examination. Following the three evaluations, each video tape were examined and analyzed by the two authors. This process was divided into three steps. First, problems for the test subject on the fore deck were identified by going through the video while listening only to speak from the fore deck.

Secondly, problems for the test subject on the bridge were identified by going through the video while listening only to speak from the bridge. Finally, the videotapes were examined while listening to speak from the fore deck and the bridge simultaneously in order to identify further usability problems. This video examination and analysis was done in a collaborative effort between the two authors allowing an immediate discussion of each identified problem. The analysis resulted in a list of usability problems describing each problem as experienced by the test subject.

4. RESULTS

The results of the study have been divided into two categories 1) total numbers and characteristics of identified usability problems 2) problems related the collaborative assignment.

The heuristic inspection identified a total of 29 distinct usability problems whereas the think-aloud evaluation identified a total of 37 distinct usability problems. Hence, the think-aloud evaluation identifies a larger number of usability problems than heuristic inspection. Of all the 29 and 37 problems of the two approaches, only 6 problems were identified by both think-aloud evaluation and heuristic inspection. As an example, the lack of opportunities for canceling actions is identified by both approaches. In the think-aloud approach, only one test subject discovered this problem. Another problem identified by both approaches is the difficulties in recognizing commands for either the aft or fore deck of the ship. In the think-aloud approach, this actually caused problems and confusion in the interaction since test subjects would try to initiate actions or missed or ignored commands. The rest of the problems discovered in the heuristic inspection (23) highly relates to lack of consistency, lack of error messages, and avoidance of mistakes. In the think-aloud approach, the rest of the problems (31) mainly relates to confusion of performing tasks and acquiring information for performing these tasks. A number of these problems relate to the collaborative assignment.

From the 29 problems identified by heuristic inspection, 6 problems relate directly to the collaborative work task. From the 37 problems of the usability testing, 15 problems relate directly to the collaborative assignment of the task. In this sense, there is a significant difference in the number of identified problems. In the think-aloud evaluation, more problems relate to the difficulties in creating an overview of the distributed activities and tasks on the ship. E.g. all of the test subjects on deck did not have a full understanding of the status of work tasks conducted by others on the ship. Furthermore, more of the test subjects do not understand the origin of a message in the system, and hence have difficulties in understanding the meaning of commands and differentiate between commands from the bridge and reports from the deck. More of the problems identified in the think-aloud evaluation seem to indicate that the test subjects had difficulties in creating and maintaining a mental model of other users' intentions and actions. Finally, some of the identified usability problems relate to the fact that simultaneous actions and activities happen on the ship all the time. More test subjects got confused when they were performing a task and the system at the same time updates information on other activities on the ship.

5. DISCUSSION AND CONCLUSION

Previous research has shown opportunities and limitations in usability testing and evaluation of e.g. traditional computerized systems, cf. (Karat et al. 1992), and for web-sites, cf. (Kantner and Rosenbaum 1997). In this study, we have tried to explore and compare two different evaluation approaches for mobile collaborative systems. We have discovered that the two approaches applied identify different kinds and numbers of usability problems.

Our study indicates that heuristic inspection support fast generation of insight into the general usability of a mobile device using relatively low resources. However, such expert evaluations apparently provide little insight on the collaborative aspects of mobile systems. Such problems were, on the contrary, richly represented in the results produced by the think-aloud evaluation. This can perhaps be explained by the fact that the expert evaluation was conducted centralized whereas the think-aloud evaluation was distributed among collaborating test subjects.

Our study applied test subjects with no or little knowledge of the collaborative domain. However, it seems that it is possible to gain insight into the usability of a specialized mobile device without involving prospective users Compared to a usability test involving real users, we have no direct indications of the relevance of the identified problems in our study. Likewise, it seems possible to identify usability problems of a mobile collaborative system without going into the field. However, further research is needed on the recreation of a realistic use context in a laboratory setting.

Neither of the two approaches in our study revealed insight into the usability of the mobile device while users actually moved physically. It is difficult to assess the impact of this variable. Pirhonen et al. (2002) describe a possible laboratory set-up for addressing mobility issues when interacting with a mobile device.

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