Interaction Techniques for Using Handhelds and PCs Together in a Clinical Setting

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ABSTRACT
In the present study we compare interaction techniques for using handheld devices together with stationary displays in a hospital setting. A set of prototype implementations were developed and tested for a pre-surgery scenario with pairs of physicians and patients. The participants were asked to rank the interaction techniques in order of preference. The results show highest ranking for a distributed user interface where the GUI elements reside on the handheld and where the stationary display is used for showing media content. An analysis of the factors affecting the usability shows that in addition to GUI usability, the interaction techniques were ranked based on ergonomic and social factors specific to the use situation. The latter include the physicality of the patient bed and how computing devices potentially interrupt the face-to-face communication between physician and patient. The study illustrates how the usability of interaction techniques for ubiquitous computing is affected by the ergonomic and social factors of each specific use context.

Author Keywords
Interaction techniques, mobile computing, multi-device user interfaces, electronic patient records, ubiquitous computing, usability.

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces - Interaction Styles; Input devices and strategies; Theory and methods.

INTRODUCTION
Handheld devices are currently widespread and are often used in environments with a wide variety of other electronic equipment such as other PDAs, other mobile phones, PCs, projectors, and TVs. We use handheld devices at work, in our homes, and in public places. Looking only at the hardware, Mark Weiser's dream of Ubiquitous Computing [14] seems close to being a reality. Unfortunately, the current lack of network, software and user interface interoperability makes reality very far from Weiser's vision.

In Weiser's 1991 future scenario, the Tab, Pads and Liveboards were truly integrated:

"A blank tab on Sal's desk beeps, and displays the word "Joe" on it. She picks it up and gestures with it towards her liveboard. Joe wants to discuss a document with her, and now it shows up on the wall as she hears Joe's voice…… She gestures again with the "Joe" tab onto a nearby pad, and then uses the stylus to circle the word she wants…".

Fifteen years later we have the building blocks, but this kind of integration is still science fiction.

There are a number of reasons why integration of devices and systems is difficult, ranging from organizational issues to lack of operating systems support for multi-device applications, and problems related to security and privacy. In addition, interoperability gives rise to new usability challenges. The usability of a system of devices is not only the sum of the usability of each separate device, but the usability of the system as a whole.

A number of interaction techniques have been developed for multi-device interfaces (e.g. [11,12]), and some of these techniques have been empirically tested and compared (e.g. [5,10]). Most of the usability evaluations have been done either with abstract tasks or with use scenarios from office work and leisure. Little is known about the usability of these techniques in other use settings.

One setting with a large potential for system integration is the hospital. Empirical studies of work in hospitals show that clinical work is information and communication intensive and highly mobile [1,2]. To best support health workers in their everyday work, the hospital's electronic patient record (EPR) system should provide access to relevant medical information at the point of care. A number of studies of existing systems have documented the benefits of mobile computing in health care [7], and other studies indicate additional benefits from the use of context

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information such as the health worker's location and electronic patient identification (RFID/Barcodes) [3,8].

In many hospitals, patient beds are now being equipped with bedside PCs for entertainment and internet access. Some bedside PCs also allow health workers to use them for accessing the patient's medical record. Compared to a health worker's handheld device, the bedside PC provides a larger display and allows for sharing screen content with the patient. Unfortunately, bedside PCs often require time consuming logon procedures and have limited input capabilities.

An alternative to having to choose between the two devices is to allow the health worker to treat the handheld and the PC as one system, thus combining the best of the two. To our knowledge no EPR system has taken advantage of this potential for seamless integration between the patient's bedside PC and the health worker's mobile device.

In this paper we describe an experimental comparison of seven different interaction techniques for using a handheld device together with a bedside PC in a hospital ward. We first give an overview of relevant research and describe a workshop with health workers aimed at identifying typical use scenarios. We then identify seven relevant interaction techniques and a baseline technique not utilizing the PDA. We describe their implementation in a prototype system and an experiment for evaluating their usability. This is followed by an analysis of the health workers' preferences concerning the interaction techniques. Last, we identify the factors influencing the usability and discuss the implications for practitioners.

BACKGROUND

Research on interaction techniques for using handhelds and stationary displays together dates back to the PARCTAB project at XEROX PARC in the early 90s [13]. Although the PARCTABs were only partly integrated with other devices, the idea of multi-device interaction was implicit in the UbiComp vision.

In [11] Rekimoto analysed the user interface problems related to content transfer between different computing devices, and proposed the pick-and-drop interaction technique as a multi-device extension of the drag-and-drop technique. In their 1997 implementation of the system, the pick-and-drop functionality was simulated using one WACOM tablet input device for each computing device, i.e. the users were not picking up and dropping objects directly on displays, but on tablets connected to the displays. The WACOM styluses had unique IDs that were recognized by all tablets, allowing up to four users to use their individual stylus to move content between devices.

As no commercially available PDAs or computer displays come with input styluses that are uniquely identifiable, full implementations of the pick-and-drop technique have required specially made hardware for stylus identification.

In [12] Rekimoto et al. describe hyperdragging as another technique for moving graphical objects from one display to another. HyperDrag does not require specially made styluses, but requires that all devices know their physical location in relation to the other devices. Moving objects between devices is then done in a manner very similar to how most current windowing systems allow for multi-display desktops. When an object is moved to the border of one display, it reappears on the display that is physically next to it or surrounds it. In the multi-display desktops in standard windowing systems, the user has to tell the system about the physical configuration of the displays. In Rekimoto et al.'s implementation of HyperDrag, the information about the device topology was acquired through wall mounted cameras that read 2D barcodes on the devices.

A number of projects have explored multi-display and multi-device solutions for specific use settings. The iRoom [4] is an augmented meeting room, allowing users to move information between a number of shared wall-mounted displays and individual laptop computers and PDAs.

Tailor-made vs. off-the-shelf hardware

Unfortunately, most multi-device systems require tailor-made hardware and special instrumentation of the physical environment. This makes large-scale implementation difficult.

The Pebbles project [9] is an example of research taking a more practical approach. Instead of requiring additional equipment such as advanced sensors and roof-mounted cameras, they start out with off-the-shelf products (e.g. PDAs and PCs) and explore how these commonly available devices can be integrated. The project has resulted in several interesting applications developed as proofs of concept. References to each application can be found in [9].

RemoteCommander is an application that lets several people control a PC from a remote location using their handhelds. A picture of the PC screen can appear on the handheld as the full screen downscaled, or as zoomed in on parts of the screen.

SlideShow Commander is an application that runs on a handheld and allows the user to control a slide show running on a PC. In addition, the user can use the handheld to change slide content and look at slides.

The Command Post of the Future (CPoF) is based around a large screen display with multi-modal input and laser pointing. The users each carry a handheld device that enables them to interact with the large display.

Shortcutter allows users to create shortcut widgets on the handheld to control any PC application.

The *Personal Universal Controller* (PUC) automatically downloads a specification from a device or appliance that needs to be controlled. The specification contains enough information for the PUC to automatically create a graphical user interface for the appliance based on the user's preferences.

Comparison of multi-device interaction techniques

Despite the high number of experimental systems integrating different devices, little is known about how the various techniques for multi-display interaction compare with respect to usability.

Nacenta et al. [10] report on an experimental comparison of pick-and-drop and five other interaction techniques for multi-display interfaces. They chose a meeting room setting, and designed a controlled experiments to compare the interaction techniques' usability for a simple information moving task. The user was asked to move screen content between a table-mounted tablet PC and a "desktop" projected onto the same table.

They found substantial differences between the techniques, and gave useful guidelines for the design of similar systems.

COMPUTING DEVICES FOR A HOSPITAL WARD

Our approach is similar to that of the Pebbles project [9] in that we start out with off-the-shelf computing technology and explore the potentials for system integration at the user interface.

The present study was done in relation to a regional hospital in Trondheim, Norway where new wards are being equipped with an advanced IT infrastructure. This includes a "patient terminal" by every bed, used as an advanced hospital bed entertainment system for the patient, and a PDA as a tool for the medical staff.

Patient terminals

The patient terminal is basically a PC where all input and output is done through a touch screen. The patient terminal is mounted on a movable arm (see Figure 1), so that it can be moved according to the patient's or staff's preferences.

Figure 1. The patient terminal

The patient terminal offers a range of services, mostly entertainment for the patient. The services include IP-based radio, TV, video-on-demand, control of lights, internet access, email, games and telephony.

PDAs for the health workers

The PDA for the medical staff implements a calling system and mobile telephony. It also provides services like telephone directory, contact information, e-mail, messages, and access to medical reference books. The PDAs have built-in wireless LAN.

Integrated RFID/barcode readers

We assume that the PDAs will be equipped with token readers that enable them to identify passive tokens with unique IDs. Off-the-shelf technology with this functionality include plug-in RFID and barcode readers.

Network infrastructure

Every device in the hospital with networking capabilities can be interconnected through an IP-based messaging system. Devices with wireless networking capabilities can be connected to the network from anywhere on the hospital area. The network infrastructure makes it technologically possible for every PDA to communicate with any patient terminal and any other PDA.

RESEARCH DESIGN

Given the available technology, we want to explore and compare relevant interaction techniques for using patient terminals and PDAs together in clinical settings.

Research questions

The aim of the study is twofold: (1) To get comparable usability and user preference data for the interaction techniques, and (2) to learn what social and contextual factors affect their usability.

Evaluation criteria

ISO 9241-11 [6] defines usability as: "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". *Effectiveness* is in this ISO definition a measure of task completion and completeness.

Most existing comparison studies of interaction techniques have focused on *efficiency* measures such as input speed, error rate, and NASA TLX measures of subjective workload. These studies have implicitly taken for granted that the techniques provide necessary *effectiveness* and [user] *satisfaction*. (See [5] for an example).

For simple and well understood contexts of use, such as web browsing on desktop PCs, these assumptions can be justified. For more complex and less understood use contexts and technologies, such as ubiquitous computing in a hospital, less can be taken for granted concerning *effectiveness* and [user] *satisfaction*. This is not to say that *efficiency* will not be important for such systems, only that very little research has been done in this area, and that we first need to understand how to achieve a necessary level of *effectiveness* and [user] *satisfaction*.

Context of use

As specified in the ISO definition, the usability of a product varies with users, goals, and contexts of use. It follows that it is meaningless to talk about the usability of a product independent of these properties of use.

The ISO standard defines context of use as: "users, tasks, equipment (hardware, software and materials), and the physical and social environment in which a product is used". To be able to compare the usability of the different interaction techniques we consequently have to specify these conditions.

To obtain a necessary level of validity for the results from the usability test, the users should be real health workers, the goals should be grounded in clinical practice, and the context-of-use should be that of a typical hospital setting.

Overall research design

Given that the focus is on effectiveness and user satisfaction, and that the context-of-use is not given in detail prior to the study, the study consisted of the following activities:

1. To get input on the context of use, we arranged a workshop with health workers to identify relevant use situations and develop a core use scenario for the comparison experiment.
2. To verify the validity of the resulting scenario, the output from the workshop was evaluated by an experienced physician.
3. Based on the scenario, a set of prototypes were developed, each implementing one interaction technique for integrating patient terminals with physician PDAs.
4. All prototypes were then tested with a number of physician-patient pairs to get data on usability.
5. The tests included a cooperative card ranking session, allowing the physician-patient pairs to express their user preferences.

WORKSHOP: IDENTIFYING USE SCENARIOS

The purpose of the workshop was to find possible scenarios in the hospital setting where PDA and patient terminal could be used together.

Participants

The workshop was done with four health workers, one male physician and three female nurses. Their ages ranged from 30 to 50 years. None of them had used a PDA before, but all had used a mobile phone and they all had some background knowledge about the patient terminal. The participants formed a representative selection of users, except that no patients were present.

Location and equipment

The meeting was held in a large room in a usability laboratory, with layout and furniture allowing us to simulate a section of a hospital ward full scale.

A PDA and a patent terminal were available for the participants.

Results

When the participants came up with a new scenario, they often used the devices available to physically show how they could be used together. Occasionally they played out the scenario in front of the patient bed. The main results are presented below.

Using the PDA to identify patients

One of the participants suggested that the PDA should have a barcode scanner that could scan a barcode on the patient's wrist. This could automatically display the right patient data on the PDA or the patient terminal. She also suggested that the PDA could feel that it was near the patient terminal. She used the term "key" as a metaphor for the PDA; the PDA was the key to show patient information on the patient terminal.

Using the PDA to log on to patient terminals

The participants believed that a logon procedure on each patient terminal or room would be a very unpractical solution. They preferred a laptop that requires one logon and that would let them easily switch between many different patients. Then they suggested that the logon could be done once on the PDA and that it could be the key to logon if the patient terminal somehow could sense that the handheld was near.

PDA hiding logon, browsing and searching

The workshop participants were concerned that the patients could be confused when they watched the medical personnel logging on to various systems, browsing and searching through the patient's medical record, so they suggested that PDA could be used for this purpose. The PDA would be the medical personnel's private screen and not visible for the patient. They would use the PDA to select what information from the patient record they would show on the patient terminal. They also suggested that the PDA could display personal sensitive information that should be hidden for the patients.

PDA and patient terminal used for preoperational briefing

The focus group participants wanted to show X-ray and CT-scan images on the patient terminal screen with the purpose of explaining medical issues to the patient, especially prior to surgery.

The information that could be showed to the patient on the terminal should be simple. They believed that pages with text would be too confusing and that only images and illustrations should be displayed on the terminal.

Resulting scenario

The results from the workshop indicated that using a PDA together with the patient terminal can offer additional functionality compared to operating the devices separately. The idea that seemed most useful and realistic for the medical personnel was to let the users find and select images on the PDA and present them to the patient on the terminal.

In the resulting scenario, a physician wants to show a patient a set of X-rays prior to surgery. The physician has the X-ray images available on a PDA, and can use the patient terminal as an additional display unit.

DOMAIN EXPERT INTERVIEW

To get an expert opinion on the resulting scenario, an experienced physician was interviewed (male rheumatologist, age 45). The scenario was presented, and he was asked to validate its realism and relevance.

Results

According to the physician there are several situations where X-ray images are shared with patients. Physicians often explain the patient's diagnosis by using X-ray images as supporting illustrations. X-ray images are tangible and objective evidence and are often more convincing than the physician's explanation.

When the physician displays X-ray images to a patient, not all of the available images are used. This is mainly because not all of them are interesting, but also because showing them all might confuse the patient.

In sum, the physician confirmed the realism and relevance of the pre-surgery scenario.

IDENTIFYING CANDIDATE INTERACTION TECHNIQUES

Seven interaction techniques for using PDAs and patient terminals together were identified for the X-ray viewing application. In addition, a baseline design for the patient terminal alone was developed.

Technique A: WIMP on PC

The baseline design is a straightforward WIMP (Windows, Icons, Menus and Pointing device) interface for the selection of X-ray images on a touch screen.

Figure 2. WIMP on PC

The number of images was kept low, making the navigation a one level selection task (Figure 2). The screen was split in two, with the selected X-ray image to the right and a list of selectable image names to the left.

Technique B: Drag and drop

The first multi-device interaction technique (Figure 3) is drag-and-drop. Icons on the handheld representing information objects can be dragged and released over an icon representing the PC. The objects will then appear on the PC.

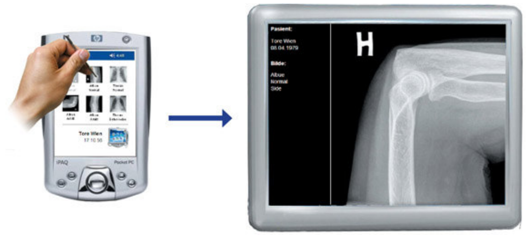

Figure 3. Drag and drop on the PDA

This is similar to how document icons can be moved in windowing systems implementing the desktop metaphor.

Technique C: Screen extension

Screen extension (Figure 4) implies that the handheld and the PC are logically interconnected so that objects can be dragged between the devices. When the user drags an object on the handheld towards the screen edge, it will appear on the PC screen.

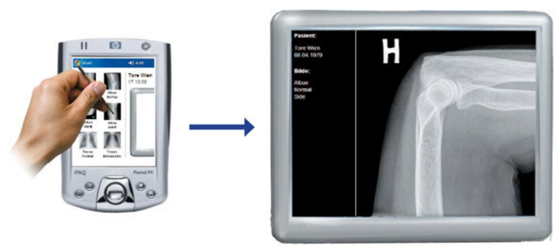

Figure 4. Screen extension

This technique is inspired by the way current windowing systems allow the user to extend the desktop over two or more screens.

Technique D: PDA as input device

Figure 5: The PDA as input device

One way of integrating PDAs and other devices is by letting the PDA replace existing input devices.

In the interaction technique show in Figure 5, the user controls the mouse cursor on the PC with the stylus on the PDA.

Technique E: Remote control

The remote control technique lets the user control the PC by tapping buttons on the handheld's screen (Figure 6). The up and down buttons let the user move between choices in menus.

Figure 6. The handheld as a remote control for the PC.

This is similar to how remote controls are used to control TVs and DVD-players.

Technique F: WIMP on PDA

The technique shown in Figure 7 is similar to the baseline design, but the WIMP navigation is done on the PDA instead of on the PC. When the user makes a selection on the PDA, the object that it refers to is shown on the patient terminal.

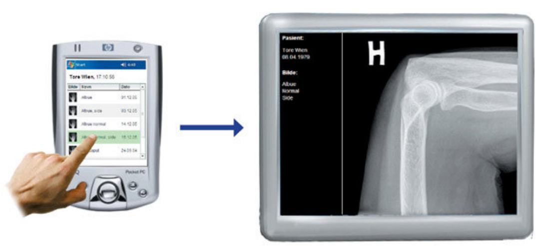

Figure 7. WIMP on PDA

All WIMP interaction is done on the PDA, while the PC display is used for showing non-interactive media content.

Technique G: Proximity

Figure 8. Proximity.

The technique shown in Figure 8 is inspired by research on tangible interfaces.

A user selects an information object on the PDA and moves the handheld towards the PC-screen. When the PDA is close enough, the selected item on the handheld is shown on the PC.

Technique H: Mirroring

Current windowing systems allow for two screens to display the same content. In our case, mirroring implies that the handheld is showing a continuously updated copy of the PC-screen where all the changes on one are reflected on the other.

Figure 9. Mirroring.

The handheld has a much smaller screen with a lower resolution, so the handheld displays a downscaled copy of the screen (Figure 9).

COMPARATIVE USABILITY EVALUATION

The aim of the comparative usability evaluation was both to get comparable usability data and to learn what factors affect the usability.

Subjects

Due to the nature of the scenario, the tests were done with pairs of users, one physician and one patient. A total of five pairs were recruited. Four of the physicians were male, one female. Their age ranged from 30 to 50. Two of the patients were male, and three were female. Their age ranged from 25 to 35.

Equipment, location and recording

The tasks were performed using prototype implementations of the eight interaction techniques described above. The proximity mechanism (technique G) was simulated by having an operator in the control room observe the users and simulate token-reader behavior.

The PDA used was a Fujitsu Siemens Pocket LOOX with built-in WLAN. The patient terminal was a standard PC connected to a 15" touch screen.

The tests were done in a full-scale model of a section of a hospital ward with roof-mounted cameras and wireless microphones used for recording. The PDA's screen content was mirrored on a PC and this image was mixed in real-time with the video and audio streams from the test. Figure 10 shows the resulting video stream.

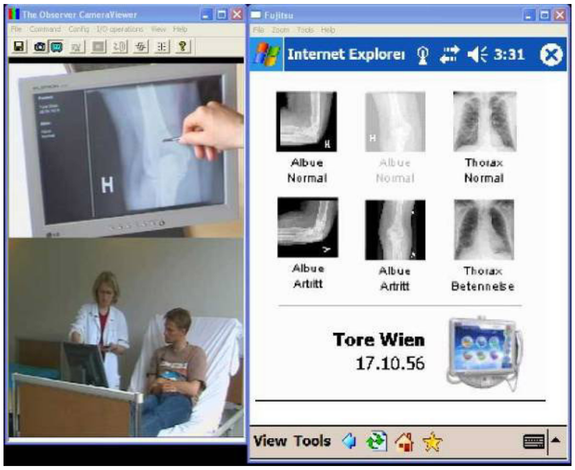

Figure 10. Video recording showing the test participants, the patient terminal, and the PDA content.

Task

The task was developed from the use scenario resulting from the workshop and the expert interview.

The physicians were given the following task description:

Your patient has arthritis in the left elbow joint. You are on a pre-surgery visit. Your task is to inform the patient about his/her condition and the coming surgery. To support your explanation, you may show the patient the X-ray images you have available.

You have seven X-ray images available. Two of the images are from the elbow joint with arthritis and two images are from the other elbow joint which is not affected (side and front views for both). There are also three images available of other patients. The purpose of the latter is to have information available that is not relevant for this patient.

The patients were asked to behave as if they were hospitalized with an elbow in need of surgery.

Both physicians and patients were instructed to communicate as they would have done in a real clinical situation.

Procedure

The physician first got a general introduction to the PDA. The patient was placed in the bed and the physician was asked to stand beside the bed with the PDA.

After trying an interaction technique, the physician was asked how he/she liked it. The patient was then asked the same, and the two were encouraged to discuss the technique together. These steps were repeated for each of the eight interaction techniques. For technical reasons the order of presentation was the same for all test pairs.

After trying all interaction techniques, they were asked to use card ranking to give their order of preference for the eight techniques. The reason for using card ranking was to make it easier for the test subjects to remember and compare the interaction techniques. They were given eight cards, each representing one interaction technique. The physician was responsible for the ranking with support from the patient.

RESULTS

Usability tests

All five pairs were able to complete the task with all eight interaction techniques. In most of the cases, all four available X-ray images of the patient's arm were displayed by the physicians. The images irrelevant for the scenario were only shown in a couple of cases where the physicians accidentally made wrong selections.

All participants commented on all interaction techniques, and all pairs played their roles in the scenario all eight times.

The physicians and patients all reported that they found it very useful to be able to see X-rays on a bedside terminal.

Technique A: WIMP on PC

None of the physicians had any problems using the patient terminal touch screen directly, and all of them seemed to find it easy to use. They presented the X-rays fast and naturally, and explained at the same time to the patient.

The patients all reported that this was a very good way to get information about their condition. One of the patients wanted to press the screen, but the rest were content letting that the physician be in control. A typical patient comment was "It was very useful to get a visual and oral explanation of how it looks. It is easier to understand."

One of the physicians described the interaction technique; "Very simple, very instructive. I'm not used to touch screens, but provided that everything is ready when you see the screen and that I can avoid problems using it, this seems like a very good solution".

Technique B: Drag and drop

Three of the five physicians expected the image to immediately appear on the patient terminal when they tapped the corresponding icon on the PDA (as in technique F). They needed a hint from the moderator to understand that they had to drag the icon.

Two of the physicians asked where the image icon should be dragged. The patient terminal icon had a different appearance than the real patient terminal, and some physicians pointed this out.

Two of the test subjects tried to drag the image back again from the patient terminal icon to its original place, explaining that they thought the image was inside the patient terminal icon and had to be dragged back in place.

One physician explained that she was sending the image from the PDA to the patient terminal. Another said that he was grabbing hold of the image.

Having learned the interaction technique, all test subjects found it fast and easy to use.

Technique C: Screen extension

Three of the physicians saw this technique as another implementation of drag and drop. Two saw it as a screen extension or a shared desktop.

We contribute this ambiguity to the way this interaction technique was implemented.

Technique D: PDA as input device

Most of the users felt that this interaction technique was awkward and pointless, especially because the patient terminal was so close that it could be touched directly. One of them said; "I don't see the benefit compared to pressing directly on the screen. But if the screen is positioned on a remote wall, this could be an alternative".

Two of the physicians suggested moving the menu on the terminal onto the PDA instead of using the PDA to control the mouse cursor. Their suggestion is equal to the *WIMP on PDA* approach, and they suggested it before they had tried that interaction technique.

Technique E: PDA as remote control

This interaction technique led to a lot of focus shifts between PDA and patient terminal. This took focus away from the patient, and some physicians commented that it was easier to press on the patient terminal directly.

Technique F: WIMP on PDA

All of the test subjects found this interaction technique very easy and fast to use.

Some of the physicians thought that this method was like moving the menu from the terminal to the PDA; "This was one of the simplest. I can go directly on a menu choice. This is the same as touching the screen [patient terminal] directly."

The problem with demanding focus changes tended to be reduced; "I can, with one look and one tap, move the focus over there and have shared focus with the patient." Another user said; "I think that this approach is so simple that I believe it doesn't disturb the dialog with the patient more than using that [the patient terminal] directly." The patients felt that they got less disturbed with this method.

There were still physicians that felt that the problem was not completely gone; "When I'm in a dialog I do not want to focus on anything else than the patient and a common object. This [the PDA] comes between us."

One physician described the benefits of having the list on the PDA rather than on the patient terminal; "It's better to lift up one and one [image] and place them on this notice board than showing a lot of information at the same time."

Another physician explained how introducing a computer tool can be a disturbing element; "Older people don't handle that. Using a PDA, which is a disturbing element, to show pictures on a screen comes between the physician and the patient. I'm surprised I'm saying this, because I'm usually a big PDA-fan".

Technique G: Proximity

Most physicians found it awkward and unnecessary to have to move the PDA towards the patient terminal. Others were more positive; "I feel that I am involving the patient more by doing this movement [moving the PDA towards the patient terminal]."

None of the test subjects understood that the proximity mechanism was simulated with a Wizard-of-Oz technique.

Technique H: Mirroring

During the tests, the physicians' focus switched to the patient terminal as soon as an image was selected. Most of the users did not make use of the image on the PDA. The small PDA screen made the menu difficult to see. One physician put it: "I find no value in seeing the same on the PDA and on the screen [patient terminal], because it is on the screen things happen. Besides, the menu becomes smaller and harder to read."

Summary of findings

Based on the observed usability and the comments made during the tests, we conclude that techniques A (WIMP on PC) and technique F (WIMP on PDA) were the two most preferred. The remaining techniques all gave rise to more usability problems.

Preference ranking results

The user preference ranks were coded from 7 (most preferred) to 0 (least preferred). The rank sum medians and 95% confidence interval lower and upper values from a Wilcoxon Signed Rank test are shown in Table 1 (exact CL=94.1%).

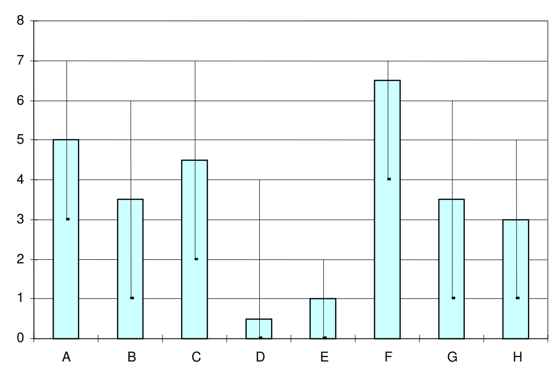

Table 1. Preference data: medians and lower and upper values (exact CL=94.1%).

We see from these data that technique F (WIMP on PDA) has the highest rank, followed by technique A (WIMP on Patient Terminal). Three out of five pairs ranked technique F as best and two pairs ranked it as next best. One pair ranked technique A as best, while two ranked it as next best. Technique C (screen extension) was ranked as best by one pair. The low number of participants result in a high variance, and the results should consequently only be taken as indications of trends.

A Friedman test on rank difference gave $p = .007$, i.e. at least one of the techniques is preferred over at least one other. A pairwise Dunn's post test gave significant differences ($p < .05$) only for the pairs D-F and E-F.

Factors affecting the usability of the techniques

The comments made in the tests and during the card rankings gave insight into the factors that were perceived as influencing the usability. All factors listed below were found for all test pairs.

User interface usability

First of all, the usability of the user interfaces as such was important. If the users did not understand how to use the prototype, or if it was awkward to use, the corresponding card was placed towards the bottom of the stack in the preference ranking.

The usability of the user interface is here defined as what is normally evaluated with a stationary usability test on a desktop computer with only one user. It includes the visual design, the ease of use of the interactive screen elements, and factors such as affordance, constraints, visibility, feedback, and interface metaphors.

In addition to user interface usability, a number of other factors emerged that were related to the mobile work situation and the physician-patient relation.

Ergonomics and screen sizes

The comments from the participants confirmed our hypothesis that the patient terminal would be an acceptable medium for showing X-rays, while the screen of the PDA would be too small.

Having the patient terminal positioned by the bed within arm's reach from the patient made it easy to see for both physician and patient. It made it easy to operate through touch for the patient, but some physicians felt that it was a bit cumbersome to operate the touch screen as they had to bend over the patient's bed to reach it.

Some physician commented that a good thing with having a PDA was that they no longer had to bend over the patient's bed to operate the terminal.

Shared view vs. hiding some information on the PDA

One recurring issue during the interviews was whether the selection list should be on the patient terminal or on the PDA.

Most physicians thought at first that there was no point in hiding the list for the patient, while some of them meant that the list could distract the patient. They were afraid that the patients would interpret information on the list without having the skills to do so.

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

Overall, there was no agreement, neither between physicians or patients, as to whether the physician should be "allowed" to have "secret" information on the PDA. The arguments for allowing some of the information to reside only on the PDA were related to screen real estate and hiding of unnecessary information, while the arguments for sharing all information on the patient terminal were related to trust and access to information.

Focus shifts and time away from the patient

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

The results from the usability test showed that the change of focus between the PDA and the patient terminal was quite demanding for most of the physicians, and it seemed to become a disturbing element in the communication with the patient. The observations indicate that interaction techniques requiring many focus changes between the PDA and the patient terminal, such as *PDA as input device* and *Remote control*, were rated lower than less demanding methods such as *WIMP on PDA*.

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

DISCUSSION

Combining the results

The low number of participant does not allow for very strong conclusions, but the combined results from the usability evaluations and the preference rankings indicate that technique F (WIMP on PDA) was preferred by most. The combined results also indicate that the difference in preference between technique F and technique A (WIMP on PC) is very small. The remaining techniques were seen as less fitting than these two, with techniques D (PDA as input device) and E (PDA as remote control) as the least preferred.

Threats to validity

With only five test pairs, one should not expect to get highly significant differences in user preference rankings. The fact that the combined results confirm the trends from the rankings gives more credibility to the results.

Due to technical reasons the evaluations were done in the same order for all test pairs. A random order might have given different results for the usability evaluations, but we believe that it affected the post-test preference ranking to a lesser degree.

Concerning the factors affecting the usability, there was a high level of agreement between the test pairs. We are consequently confident that these results are sufficiently statistically significant (sign test of five out of five gives p=.06).

Limitations of the scenario

The current scenario assumes that the logical link between the PDA and the patient terminal has already been established. We have not dealt with issues related to authentication, logon, and device identification. An extended scenario might have led to a different ranking of the interaction techniques.

Further research is necessary to conclude on this. The prototypes would then have to be extended with interaction techniques for authentication and for identification of devices and users.

CONCLUSIONS

The aim of the present study has been to evaluate the usability of a set of relevant interaction techniques for using PDAs together with bedside PCs in a hospital setting. The focus has been on user satisfaction and factors affecting the usability.

The techniques were evaluated by pairs of physicians and patients. The interaction technique WIMP on PDA was preferred by most test pairs, closely followed by the baseline technique WIMP on PC that did not utilize the PDA.

The factors affecting the usability were: (1) the usability of the graphical user interfaces, (2) ergonomics and screen sizes, (3) preferences concerning showing information on a shared display, and (4) focus shifts and time away from the patient.

We conclude from these results that designers of systems integrating handhelds and stationary displays in hospitals should pay special attention to factors beyond the user interface such as the physical properties of the setting and the social aspects of the physician-patient interaction.

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