Interaction Design for Handheld Computers

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ABSTRACT

Interaction design for handheld computers challenges our basic knowledge about human-computer interaction. Displays are small due to limited physical size of the devices and interaction is limited due to handheld operation. While a lot of effort is being put into the development of new means of input and the design of miniature graphical interfaces, little research is reported on the usability of the variety of already available input devices for handheld computers in relation to common styles of interaction being used. Reporting from an empirical usability experiment, this paper addresses the relations between input devices commonly available on mobile devices today and classical styles of interaction described in HCI research literature. The question asked is simple: how does which input devices fit which interaction styles?

Keywords: Handheld computers, mobile interaction, input devices, interaction styles, usability evaluation

1. INTRODUCTION

Handheld computers take various forms supporting both general and highly specialized use. Personal digital assistants provide calendar-like functionality and applications useful when traveling such as simple tools for communication and information retrieval, miniature office applications and applications for leisure and entertainment. In the more specialized end, mobile phones primarily support spoken and written communication but typically also provide simple applications for managing the user's address book etc. Some mobile phones furthermore support simple Internet browsing. Other handheld computers have even more dedicated functionality such as e.g. GPS positioning and route planning devices, MP3 players, infrared bar code readers or pocket calculators. Though diverse, these devices share the problem of interaction design.

Squeezing complex functionality into the interface of a pocketsize computer and putting it in the hand of a mobile user represents a serious interface and interaction design challenge. Displays are small due to limited physical size of the devices and interaction is limited due to handheld operation. This challenge requires additional knowledge about human-computer interaction in a mobile use context to be obtained.

The purpose of this paper is to discuss the relevance and compare the usability of *traditional* input devices and styles of interaction for handheld computers. We specifically compare the usability of three different input devices in relation to three different styles of interaction, providing a list of properties describing the relations between the two being useful when matching interaction styles to available input devices and visa versa.

The paper is structured in the following way. In the next section, we approach the issue of interaction design for handheld computers, stressing the relevance of extended knowledge about the usability of traditional means of interaction in this context. In section three, we line up a number of commonly available input devices for handheld computers today, describing their immediate properties and limitations. In section four, we then turn our focus towards the use of traditional interaction styles such as menu selection, form filling and direct manipulation in the context of handheld computers.

The comparison of input device and interaction style relations are based on an empirical usability experiment. In section five this experiment is described, followed by an outline of our findings in section six. Finally we conclude on the discussion and point out limitations and avenues for further work.

2. INTERACTION DESIGN FOR HANDHELD COMPUTERS

Interaction design for handheld computers is approached from various perspectives including the development of new technologies as well as creative exploration of existing ones. A lot of effort is specifically being put into the development of new means of input such as speech [1], environmental sensors [2] and context awareness [3] etc. In parallel, a lot of research is done within the design of miniature graphical interfaces [4], the exploration of multi-modal output [5] and the use of alternative display technologies e.g. build into ones eyeglasses [6][7].

Studying the research literature on mobile HCI one thus quickly gets the impression that interaction with mobile computers could soon be fundamentally different from traditional computer use.

Nevertheless, most commercially available handheld computers today are still dominated by the use of rather traditional means of interaction design known from the human-computer interfaces of graphical desktop computers. For a quick overview of the design of mobile device interfaces see e.g. [4]. The interactions design encouraged by general handheld operative systems such as PocketPC, PalmOS, EPOC and Symbian thus to a large extend resembles that of their desktop counterparts in a miniature scale.

While the use of human-computer interaction techniques originally developed for desktop computers may without dispute be inconvenient in *some* mobile use contexts, this approach yet seems to have a huge justification. The immediate advantages are obvious. People are used to interacting with computers through windows, icons, menus, pointers and function keys throughout years of experience with personal and office computing. Applying the same approach to interaction design with handheld computers, users can benefit from well-known conventions of design and use. Similarly, designers are used to express and communicate the functionality of systems through such interfaces throughout years of system development practice.

Designing and using fundamentally *new* kinds of interfaces for handheld computers thus involves both users and designers to throw out some of their existing knowledge and start over again: develop and assimilate new conventions of human-computer interaction. If not gaining immediate significant quantitative and qualitative improvements of technology use such as increased effectiveness, lower rates of error and higher subjective satisfaction, the effort of designing and learning new interaction design may not be worth the while from neither a developer nor a user perspective: if it pretty much works as it is… why change it into something that might not be better? In this perspective, however, knowledge about traditional means of interaction in the context of mobile computing is important.

2.1. Input Devices and Interaction Styles

The usability of any interaction design depends on the relation between *interaction style* and *input device.* Whereas input devices are typically physical artifacts like keyboards, pointers, joysticks, microphones, cameras etc., interaction styles represent ways by which the specific input from these devices is translated and used by the computer application such as e.g. direct manipulation, command language or menu selection.

The HCI literature often presents the choice of input devices as a matter of suiting the desired interaction style best [8][9][10]. Alphanumeric keyboards are chosen for text entry. Mice are chosen for direct manipulation and virtual reality gloves are chosen for three-dimensional interaction. Within the context of handheld computing, however, one may argue that this relation is reversed because the available means of input are typically limited.

Despite a huge diversity of functionality and use, most handheld computers are characterized by facilitating the same input devices. While the use of alphanumeric keyboards and indirect-pointing devices; mice, trackballs and joysticks is limited within the context of handheld computing due to physical size and lack of support for mobile operation, numerical keyboards, direct-control pointing devices (such as pens and touch screens), cursor-movement keys and function keys are highly prevalent. Numerical keyboards are used for entering numbers and text on mobile phones. Direct pointer are used for selecting and manipulating elements on graphical displays or for recognizing handwriting. Cursor movement keys/scroll wheels are used for browsing lists of information such as one's phone book and function keys are used for activating dedicated functions such as answering a call or starting the voice recorder application.

The usability of these input devices have been thoroughly evaluated in relation to desktop computing and documented in the HCI literature (e.g. [8][9][10]). However little similar research has been reported on the usability of the different input devices typically facilitated on handheld computers in relation to the traditional styles of interaction, which is often applied [4]. Limited knowledge thus exists on how these interaction styles perform in relation to the available input devices for handheld computers. The question is simple: how does which input devices fit which interaction styles?

3. INPUT DEVICES FOR HANDHELD COMPUTERS

In the context of handheld computing, numerical keyboards, cursor-movement keys, function keys and touch screens share the property of being relatively small and naturally embedded into the devices controlled by them. Furthermore, most of these input devices can potentially be operated with the same hand that is also holding the device.

Function keys on handheld computers specifically have the advantage of supporting quick access to frequently used applications or functions. Function keys are often labeled with icons or text but sometimes simply signal their functionality through their shape and/or location on the device, known as natural mapping. The use of function keys is normally restricted by the limited number of functions potentially assigned to each of them. A common solution to this problem is to have different functions assigned at different times according to the state of the device or application (known as soft keys).

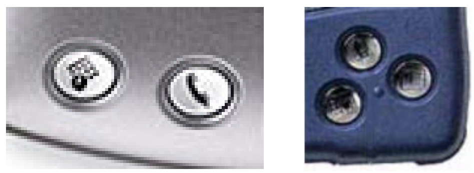

Figure 1. Function keys on handheld computers

Cursor movement keys on handheld computers are typically used as a more general purpose input device than function keys. Cursor keys embedded into handheld computers have the advantage of being naturally mapped to the physical layout of the device controlled by them. Cursor keys are typically either shaped as or labeled with arrows or grouped into multidirectional buttons, as illustrated below. While function keys have affordances for discrete input (single clicks), cursor keys are typically *also* used for continuous input (click and hold). The use of cursor keys is restricted by the limited speed of use compared to e.g. direct or indirect pointing devices.

Figure 2. Cursor keys on handheld computers

Direct pointers for handheld computers exploit the fact that a graphical display is typically embedded into the device. Pointing directly on the screen using ones finger or by means of a pen are obvious affordances of such design. Direct pointers are primarily limited by the demand for two-handed operation, the need for a separate pointing device, the lack of precision while moving and the visual occlusion of the display while pointing. Like cursor keys, direct pointers have affordances for both discrete input (selecting) *and* continuous input (dragging/writing).

Figure 3. Direct pointers on handheld computers

4. INTERACTION STYLES FOR HANDHELD COMPUTERS

While available human computer interaction styles are numerous [8][9][10], only a few styles of interaction are being widely used within the area of handheld computing. Performing a quick survey into a broad range of applications commercially available for handheld computers, three styles of interaction are clearly dominating the picture:

- Menu selection
- Form filling
- Direct manipulation

Figure 4. Menu selection, form filling and direct manipulation in graphical interfaces for the PalmPilot

Menu selection is widely used in handheld computer interfaces. Menu selection has the advantage of supporting the representation of a large number of possible actions in a relatively limited space using only simple means such as written text and small icons. This is essential when designing for small displays with limited graphical performance. Furthermore, interaction design based on menu selection is highly versatile. Selecting an item or action from a menu can be done in various ways: e.g. by entering a corresponding number for each line or selecting a specific line either by browsing the list or pointing it out. This versatility facilitates the use of various input devices: numeric keyboards, cursor keys and pointers.

Form filling is also very common in interfaces for handheld computers. Contrary to menu selection, form filling is used for entering more complex input where a list of all possible choices cannot be provided or would be too comprehensive, such as names, addresses or phone numbers. Form filling has the advantage of guiding the user through the interaction and structuring user-input by explicitly indicating what information is required at a specific time and where to put it. Form filling demands interaction on two levels. First, the field to be filled has to be selected. Secondly, input has to be entered (either text or numbers). While fields of a form can be selected much like the elements in a menu, entering text and numbers into the fields is often problematic on a handheld computer, limiting the use of this interaction style. The suggested solutions are numerous depending on available input devices: from handwriting recognition and word prediction, to picking letters on a virtual keyboard using a pen or browsing through the alphabet using a set of dedicated keys.

Direct manipulation interfaces in which the user selects and manipulates virtual objects on the screen are prevalent in handheld computer interfaces but not as commonly used as menus and forms. Although some applications allow the user to pick and manipulate virtual objects directly on the screen, direct manipulation on handheld computers is primarily used for e.g. drawing, selecting and moving text and for operating menus and forms.

According to Shneiderman [8], when it is not possible to create appropriate direct-manipulation interfaces, menu selection and form filling are good alternatives.

5. THE EXPERIMENT

An experiment was conducted evaluating the usability of the three described input devices for handheld computers in relation to the three described styles of interaction. This section explains the design of that experiment.

The experiment was divided into two phases. First, a series of experimental prototypes were designed and implemented for handheld computer use with the scope of comparing the relations between input devices and interaction styles discussed above. Secondly, a usability evaluation of these prototypes was carried out. A development and evaluation team of three people designed and implemented the prototypes and conducted the usability evaluation.

The experiment was inspired by earlier work evaluating the usability of different input devices in relation to *one* style of interaction [11] and evaluating the usability of a number of different interaction styles in combination with *one* specific input device [12]. While these experiments, however, varied only one parameter (either input device or interaction style), we decided to set up at matrix of the two, allowing us to evaluate several combinations.

5.1. Experimental prototypes

Three different prototypes of the same information service facilitating simple browsing of movies and reservation of seats in a fictive cinema were implemented for use on a handheld computer.

Each prototype of the information service required the use of form filling, menu selection and direct manipulation but was designed for interaction through only one of the three input devices: function keys, cursor keys or direct pointer.

The prototypes were based on analysis and design conducted using the ETP method [13] for object modeling and user interface design. The implementation was done using Microsoft embedded Visual Basic 3.0 and a software development kit for PocketPC.

The following illustrations show the interface design for interaction using a direct pointer.

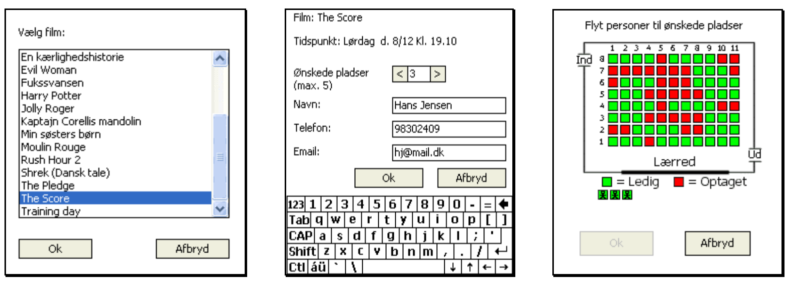

Figure 5. Menu selection, form filling and direct manipulation for experimental cinema information service

1. Selecting a movie from the list
2. Entering number of seats and contact information
3. Specifying the desired vacant seats

5.1.1. Selecting a movie

On the first screen, the user is requested to select a movie from a menu. Using function keys, the list can be divided into two (upper or lower half) until only one item remains. Using Cursor keys, the user can scroll up and down until the desired item is highlighted. Using a direct pointer, the user can select an item by clicking on it.

5.1.2. Entering contact information

On the second screen, the user is requested to enter number of seats and fill in contact information (name, phone number and e-mail address) into a simple form. Using dedicated function keys, the user can browse through the alphabet letter by letter, acknowledge a letter and jump to the next field. Using the five way-cursor key, the user can similarly browse the alphabet (left/right), acknowledge a letter (middle) or jump to the previous or next field (up/down). Using the direct pointer, the user can point at a specific field and select each letter one at a time from a virtual keyboard on the screen.

5.1.3. Specifying seats

On the third screen, the user is required to specify the desired seats by moving the icon of a small group of people (corresponding to the selected number of seats) to the preferred vacant location in the cinema by means of direct manipulation. Using function keys, the group of persons can be moved one step left or one row down. When reaching the desired location, this can be acknowledged by pressing a third dedicated button. Using cursor movement keys, the group can be moved up/down or left/right. Location is acknowledged by pressing the center of the button. Using the direct pointer, the group of people can be dragged to the desired location, which is then acknowledged by clicking the "ok" button.

5.1.4. Hardware

The prototypes were targeted at a Compaq Ipaq 3630 handheld computer with 32MB RAM and a color display of 240x320 pixels running Microsoft PocketPC. This device facilitated interaction by means of four function keys and a five-way cursor movement button located below the display, or by touching the display using either ones finger or a dedicated pen as depicted on figure 6.

Figure 6. Function keys, cursor keys and direct pointer on Ipaq

5.2. Usability evaluation

An evaluation of the interaction design implemented in the experimental prototypes described above was carried out. The evaluation was conducted at a dedicated usability laboratory at the University of Aalborg, DK.

5.2.1. Participants

A total of 21 male and female students of computer science or informatics at the University of Aalborg participated in the usability evaluation. The test subjects were equally distributed among the three prototypes according to their study orientation, sex and experience with the use of PDAs. Each test subject was assigned to one of the three input devices and used this in combination with all three styles of interaction. Seven users thus tested each input device.

5.2.2. Experimental procedure

The usability evaluation was divided into two phases. First, each user was given a brief lesson in the principle and use of the input device and interaction styles to be evaluated. The prototypes supported this through a simple tutorial application. Hereafter, the user carried out an overall task, using the dedicated input device.

5.2.3. Tasks

The overall task to be carried out by the test subjects consisted of three more specific tasks corresponding to the scope of the prototypes. 1) Selecting a specific movie from a list using menu selection. 2) Specifying number of seats and entering personal information using form filling. 3) Specifying the desired seats using direct manipulation

5.2.4. Data collection

Time spend on each task was automatically registered through a time log module build into the prototypes, generating a log file following each evaluation. User interaction with the handheld computer was furthermore recorded on audio/video tape and notes regarding the user interaction or comments were taken during the evaluation.

5.2.5. Data analysis

The primary dependant variables of the experiment were task completion times for each of the nine combinations of input devices and interaction styles. Based on the task completion times, we have calculated and compared total and average completion times as well as standard deviations for input devices, interaction styles and users.

5.2.6. Limitations

As the three interaction styles applied in the prototypes were assigned to the solution of different and incomparable tasks (see 5.2.3.) the time spent using each of the interaction styles cannot be compared directly.

6. FINDINGS

In this section, we present and discuss the findings from the experiment. The evaluation shows that direct pointing devices are very versatile and can be successfully combined with any of the three interaction styles. Cursor keys also prove useful in combination with menu selection and direct manipulation while less successful for form filling. Function keys generally have the lowest performance.

6.1. Task Completion Time

The following figures 7-9 show an overall view of measured task completion time for test subjects grouped in accordance to interaction styles and input devices.

Figure 7 shows a variation of task completion times for form filling with reference to the interaction devices used. Direct pointers are clearly in favor. A variation among the test subjects of each interaction device for form filling is also indicated with ranges of task completion times for function keys, cursor keys and direct pointer of 72, 60 and 22 respectively. Again, direct pointer is the favored device with least dispersion.

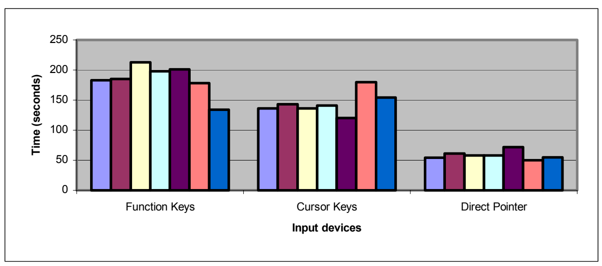

Figure 7. Completion times for form filling

Figure 8 identifies a similar variation of task completion times for menu selection in relation to the interaction devices used. Function keys are clearly being more time demanding than cursor keys and direct pointer. A variation among the test subjects is also indicated. With ranges for function keys, cursor keys and direct pointer of 18, 11 and 7 respectively, the dispersion of task completion time is however considerably smaller than for form filling.

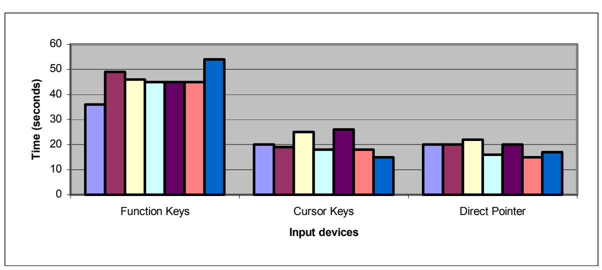

Figure 8. Completion times for menu selection

In figure 9 the variation of task completion times for direct manipulation in relation to the interaction devices used is considerably smaller than for form filling and menu selection. Again, function keys demand more time than cursor keys and direct pointer, but the differences are not as significant as in combination with form filling or menu selection. The variation within the performance of the test subjects is, however, a bit higher than that of menu selection with ranges of 25, 14 and 14 for function keys, cursor keys and direct pointer respectively

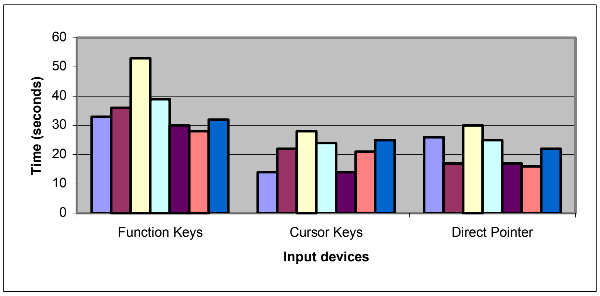

Figure 9. Completion times for direct manipulation

6.2. Total and Average Completion Time

In the following, focus is turned towards discussing and comparing the *effectiveness* of the evaluated input devices. This is done on basis of the total and average task completion time.

Table 1 shows the total and average task completion times for the nine combinations of input devices and interaction styles. These values are also depicted in figure 10 and 11. To the right, the standard deviation of the time spent on each interaction style using the three input devices is calculated.

	Function Keys	Cursor Keys	Direct Pointer	Standard deviation
Form Filling	185	144	58	52,9
Menu Selection	46	20	19	12,5
Direct Manipulation	36	21	22	6,8
Total	267	185	99	

Table 1. Average task completion times (seconds)

Figure 10 illustrates the summed average task completion time using function keys, cursor keys and direct pointer. From this figure it is clear that the use of direct pointer results in a considerably higher performance for solving the same task. The use of a direct pointer thus demanded only 37% of the time spent on function keys and only 54% of the time spent on cursor keys.

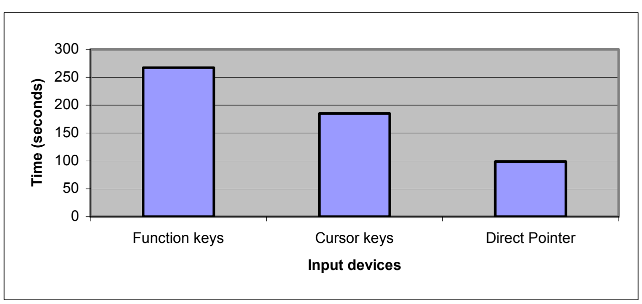

Figure 10. Total average times spent using each input device

Figure 11 shows the distribution of average task completion times for form filling, menu selection and direct manipulation using the three different input devices.

This figure shows that the primary difference in average task completion time originates in the form-filling task. The figure also shows that cursor keys and direct pointers are more or less equally suited for menu selection and direct manipulation. When it comes to form filling, however, the use of a direct pointer demanded only 40% of the time spent using cursor keys and only 31% of the time spent using function keys.

Function keys clearly have the lowest performance in combination with all styles of interaction. Menu selection with function keys consumed 130% more time than when using cursor keys or a direct pointer. Direct manipulation with function keys consumed 70% more time.

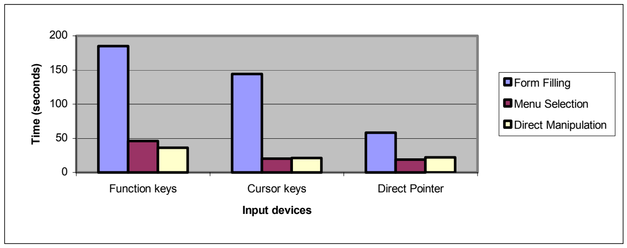

Figure 11. Average task completion times

6.3. Standard Deviations

Having discussed effectiveness, Focus is now turned towards discussing and comparing the *homogeneity* of the interaction styles evaluated and the user performance registered. This is done on basis of the standard deviations of the task completion times for the different input devices, interaction styles and test subjects.

The standard deviations in table 1 represent the level of dispersions of average task completion times for a specific interaction style used in combination with the three different input devices. These are depicted in figure 12. The dissimilar values indicate an inhomogeneous relation between input devices and interaction styles. Compared to the other two styles of interaction, the standard deviation for form filling is rather high (52,9). This implies that dispersions of task completion times are relatively large and that the performance of form filling highly depends on the associated input device. Menu selection, on the other hand, is much less sensitive to the specific input device being used (12,5) while the performance of direct manipulation interaction styles varies least in combination with the different input devices (6,8).

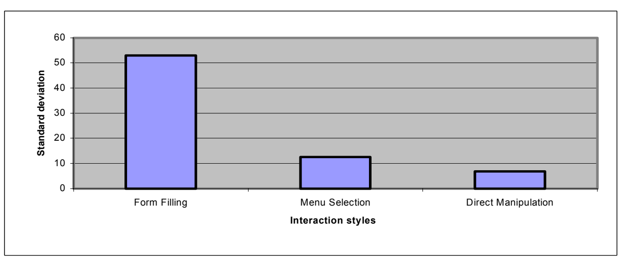

Figure 12. Standard deviations for average completion times

Table 2 show the standard deviations of the measured task completion times for the different test subjects in relation to a specific combination of input device and interaction style. These are depicted in figure 13. The values can be compared in both dimensions representing the user interaction homogeneity in relation to either input device or interaction style.

The standard deviations of these values show that users perform most homogenously by menu selection or direct manipulation interaction styles (1,1 and 1,3) and direct pointer input devices (1,7). Conversely, users perform least homogenously by form filling (7,1) and function keys (8,1).

	Function Keys	Cursor Keys	Direct Pointer	Standard deviation
Form Filling	23,5	17,3	6,4	7,1
Menu Selection	5,0	3,7	2,4	1,1
Direct Manipulation	7,8	5,0	5,0	1,3
Standard deviation	8,1	6,1	1,7	

Table 2. Standard deviations for input devices and interaction styles

The dispersions of standard deviations illustrated in figure 13 show that form filling by the use of function keys or cursor keys causes inhomogeneous and more dispersed user performance relatively to the other styles of interaction. Using menu selection or direct manipulation in combination with any of the three input devices, user performance is, however, highly homogenous.

Figure 13 also show that the use of function and cursor keys generally results in higher standard deviations among users relatively to direct pointers. This indicates that users perform less homogenously when using function and cursor keys, regardless of the applied interaction style.

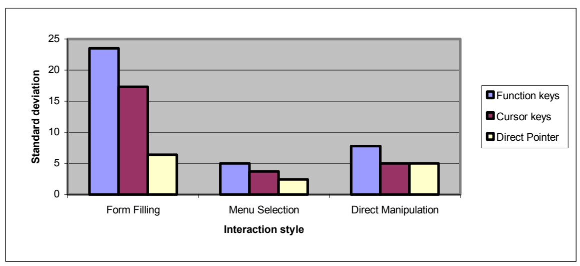

Figure 13. Standard deviations for interaction styles

7. CONCLUSION

The combination of input devices and interaction styles for handheld computers has influence on the effectiveness and consistency of user performance. The conducted experiment indicates the following specific conclusions:

Direct pointers have the best overall performance in respect to being both effective and working equally well in combination with all three styles of interaction. Furthermore, users perform most homogenously when using a direct pointer compared to other input devices.

Cursor keys perform as well as direct pointers for menu selection and direct manipulation but are less effective for form filling.

Function keys perform significantly poorer than the other input devices regardless of interaction styles and causes inhomogeneous user performance.

Menu selection supports the most homogenous user performance compared to the other styles of interaction, and performs homogenously with all input devices.

Direct manipulation performs equally effective and equally stable in combination with cursor keys and direct pointers. User performance is homogenous.

Form filling is highly sensitive to the input device being used, with a clear preference for the use of direct pointer, and causes users to perform least homogenously.

8. LIMITATIONS AND FURTHER WORK

The scope of the work presented in this paper is naturally limited by the interaction design of the experimental prototypes. The applied interaction styles might thus have been implemented differently in order to support the evaluated input devices better. This may have improved the performance of some of the input device/interaction style relations. Furthermore, the experiment is limited in the sense that the performance of the three interaction styles cannot be compared directly. Designing the experiment differently could eliminate this problem.

Further research should test the general value of the presented findings and compare the performance of various interaction styles for handheld computers in relation to different kinds of interaction tasks.

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