An Action Control but no Action: Users Dismiss Single-Handed Navigation on PDAs

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ABSTRACT

Many PDAs have controls designed to be used by the hand holding the device. If employed to a greater extent, these controls could enable single-handed navigation. To explore this, we implemented a prototype, PowerView, on the Casio Cassiopeia E-11 and evaluated it for usability against the standard (Windows CE) application bundle of the device using 16 subjects in a repeated-measurement design with seven information retrieval tasks. Subjects systematically dismissed single-handed navigation even when exposed to a condition where two-handed navigation was strenuous: standing, holding a cordless phone while simultaneously using the Cassiopeia. Neither effectiveness, efficiency, optimum path choice, mental workload ratings nor attitudes differed significantly between interfaces. Possible reasons for the results, including observed *Einstellung* effects, are discussed.

Keywords

Personal Digital Assistant, Einstellung, Mechanization, interface design, usability evaluation, usage, single-handed navigation, information visualization, information linking, Action Control.

1. INTRODUCTION

Personal Digital Assistants (PDAs) are rapidly becoming widespread among mobile workers, giving users access to digital information while on the move. However, once these users have begun to work away from the office environment, they wish to work in a number of different mobile settings. The environmental conditions in these settings do not always allow the user to interact with a PDA in the same stable and predictable conditions as in an office. This creates greater demands on the interfaces for PDAs.

Ethnographical studies have shown that in many work situations, it is not possible to require that users have two hands available for interaction with a device (Kristoffersen and Ljungberg 1999) To compensate for such limitations, many new input forms have been introduced, e.g. key cards (Sugimoto and Takahashi 1996), enhanced trackpoint devices (Kawachiya and Ishikawa 1998) and tilt-sensitive devices (Rekimoto 1996). All these allow for single-handed use of the devices, but require new or modified software.

Many commercially available PDAs already have buttons that can be used by the hand holding the device. Instead of designing new input devices, we wished to use the already present buttons to explore single-handed interaction. Currently, these are only employed to a limited extent, namely to scroll in menus, as available PDA interfaces require point-and-click interaction for nearly all operations.

In this paper, we describe the PowerView prototype that facilitates single-handed navigation and present an evaluation of PowerView against the standard application bundle of the device used. The interfaces were equivalent in usability but, surprisingly, the subjects did not even try to use the buttons that facilitated the single-handed navigation. We present possible explanations for these findings and conclude by relating them to interface design for small devices.

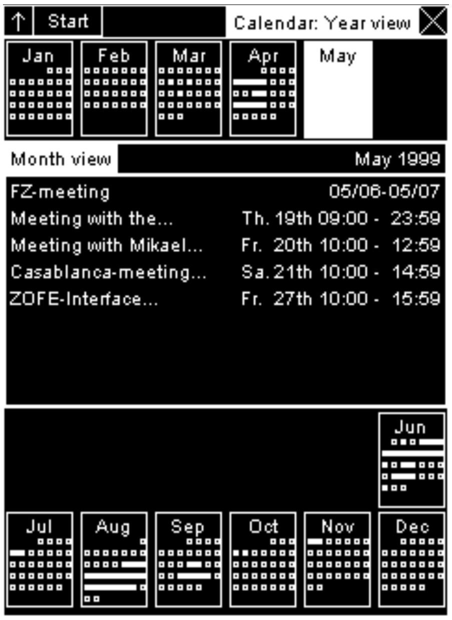

Figure 1. Screenshot of the PowerView prototype showing a full screen view (240*320 pixels) of the Calendar: Year view. In the smaller month views, days with meetings are filled and meetings longer than a day span across the empty space between the days in question. The display area is shown in actual size.

2. The PowerView Prototype

The PowerView prototype (figure 1) was implemented on a Casio Cassiopeia E-11. Even though PowerView technically is an application running under Windows CE, we refer to it as an interface, as it does not use any of the GUI components of Windows CE. The prototype provides an integrated system where the most common applications used on PDAs (address book, email client, to-do list, and calendar) are accessible. For a detailed description of the PowerView prototype, see Björk *et al.* 2000.

2.1 Information Visualization

Information visualization techniques have been shown to be effective ways of presenting information (Card, Mackinlay and Shneiderman 1999, Furnas 1986, Rao *et al.* 1995) and have recently been introduced to devices with small screens (c.f. Björk *et al.* 1999 and Taivalsaari 1999). As the Cassiopeia E-11 had a very limited display area, PowerView used the Flip Zooming information visualization technique (Holmquist 1998) to make effective use of this space.

Flip Zooming belongs to a class of information visualizations techniques called focus+context visualization. These are characterized by having one central object presenting more detailed information, i.e. the focus, while simultaneously presenting contextual information in surrounding objects. The objects are ordered sequentially, making it possible to "flip" an object into focus by navigating "up" and "down". Focus can also be moved to any visible object by the use of pointing devices. Presenting several object simultaneously differs from ordinary Windows CE applications in which only one window or application is visible at any given time.

In order to reduce the number of objects displayed on the screen, a structural hierarchy was introduced (see (Björk 2000) for previous use of Flip Zooming with hierarchies). The use of a hierarchy makes it possible to provide a clearer presentation for users, and enables more detailed information when the user moves down the hierarchy.

2.2 Information Navigation

The Casio Cassiopeia E-11 is equipped with an Action control, which combines three different actions in one button: push up, push down, and push in (figure 2). This control (together with the nearby Exit button) was programmed to allow full navigation within PowerView. The Action control is used by the hand holding the device, i.e. the non-preferred hand as the device is designed to be used with a stylus in the preferred hand. Experiments in performance using computer input devices with the preferred and non-preferred hand have indicated that the non-preferred hand is well suited for tasks such as scrolling, which do not require precise action (Kabbash, MacKenzie and Buxton

1994). PowerView was designed for information retrieval, which in Flip Zooming can to done solely be scrolling and using a select operator, but not designed to allow input of new information. This is in line with Jacob et al. (Jacob *et al*. 1994) who advocate a closer study of the interrelationship between the perceptual structure of tasks and the control properties of the device.

2.3 Information Integration

Deep hierarchies with many nodes easily become difficult to navigate (Goldstein, Anneroth and Book 1999). In PowerView, the hierarchy varied between 2 to 4 levels in depth and between 3 and 31 items in width.

Figure 2. The Casio Cassiopeia E-11 with a close-up on the Action Control. The left-hand thumb of a right-handed user is positioned on the Action Control.

As our aim was to achieve a quick retrieval of information, short-cuts were needed for traversing this hierarchy. This was partly achieved by integrating the applications, thus eliminating the need for switching between applications in order to retrieve different kinds of information.

The presentation of the top level of the hierarchy is named the *Overview view*, as it presents information of all four information types (figure 3). In the overview, information is presented in four separate views: The AddressBook, Mailbox, To Do List, and Calendar. When the user navigates into one of these views, the whole screen area is used to allow navigation within that view.

The most important step to enable rapid transversal of the information, however, was to link related information entries. This made it possible to have an integrated view, a *Context view*, of entries that have something in common. For instance, if a meeting is selected in the Calendar, the context view makes it possible to directly access information about people associated with that meeting, as well as e-mail received from or sent to them.

2.4 Using PowerView

In order to illustrate how the PowerView interface works, a sequence that show a typical interaction with the system is given. In the example, the user wishes to find out which meetings are booked with Mikael Goldstein. To do this, a search for the entry with that name is performed, so that meetings linked to this entry can later be examined in the Context view. PowerView utilizes the Action control to move between items on the screen (up/down), select item (push in) and to back up in the information hierarchy (the Exit button).

1. Initially, the user is presented with the Overview, in which information from all four different views is visible (figure 3).
2. To find the entry “Mikael Goldstein”, the user needs to search the AddressBook for this name. Using the Action control or the stylus, the user moves the focus to the AddressBook and is given the beginning of the list of names in alphabetical order (figure 4).
3. Selecting the AddressBook, the user sees a fullscreen view of all name entries. The user navigates to the letter G, and selects the entry Mikael Goldstein (figure 5).
4. The user now has focus on an individual object in the information hierarchy. Selecting that object brings the system to the Context view. Here, all views are once again shown. The difference from the Overview is that only entries linked to the chosen entry are shown, i.e. only the context of the focus object is shown.
5. To examine the meetings with Mikael Goldstein, the user simply moves the focus to the Calendar.

Figure 3. The OverView, the initial view in PowerView, with focus on the Calendar.

Figure 4. The Overview view with focus on the AddressBook. The amount of information and its presentation changes as different applications are moved into focus.

Figure 5. The AddressBook view with focus on the letter G. The selected name is highlighted. Names in non-focused objects are shown as lines.

3. EXPERIMENT AND HYPOTHESIS

In order to evaluate the usability of single-handed navigation for information retrieval tasks, the PowerView interface was benchmarked against the standard application bundle Windows CE. First, the subject was exposed to each interface when sitting. The same subject was then exposed to a standing condition with a cordless (DECT) phone in one hand, restricting the subject's freedom of interaction. The Standing condition was assumed to bias the subject towards using single-handed interaction through the Action Control. The functionality of the Action Control for the PowerView interface was enhanced compared to that of Windows CE, since *all* information retrieval operations could be performed using the Action Control alone. No difference regarding effectiveness, efficiency or attitude measures was supposed to exist between the interfaces.

Prior to the evaluation of each interface, each subject was allowed to freely familiarize with the interface for six minutes to gain a first experience. No manual was provided. The stylus and the location of the Action control were shown. Their functionality was explained, but no description of the concept or use of the interface was given. For a detailed description of the experiment, including all collected data, see Jacobsson (1999).

3.1 Experimental Design

A 2x2x7-factor (Interface (Windows CE, PowerView)) x (Posture (Sitting, Standing)) x (Task (1-7)) Within-subject GLM Repeated measurement design was adopted using the SPSS V9.0 software. A Balanced presentation order of the interfaces was administered. Significance level was set to 5%. All pair-wise comparisons were Bonferroni adjusted.

3.2 Independent Variables

3.2.1 Usability Lab and Questionnaires

The experiment was conducted at the Usability Lab at Ericsson Research in Kista, Sweden. The lab consists of two rooms separated by a one-way mirror. The test room is equipped with three video cameras enabling three different camera views to be recorded at the same time. For each interface condition, a multi-dimensional work load assessment inventory, NASA-TLX (Task Load Index) (Hart and Staveland 1988), was administered which assesses mental, physical and temporal demands as well as performance, effort and frustration level. An attitude questionnaire consisting of 8 questions was used for the final assessment of each interface. Each fixed 9-point category scale (1-9) had two bipolar descriptors as anchors. The subjects were also encouraged to write down suggestions for changes in the interfaces. Spatial ability was assessed using an inventory included in the

Standardized Swedish Delta Battery (Psykologiförlaget 1970).

3.2.2 Subjects

Sixteen paid subjects, 10 women and 6 men (age 17-43 years, M=28 years) participated, all university students. Most of them belonged to the human science faculty. None had any prior experience of a PDA. All subjects were familiar with using Windows on a stationary computer. Two subjects were left-handed.

3.2.3 Interface Types

Two interfaces, Windows CE and PowerView, were used in the experiment. Both interfaces ran on a palm-sized PDA, the Cassiopeia E-11 (height=142 mm, width=112 mm, depth=17 mm) featuring a 240 x 320 pixel gray scale touch-sensitive display area and an Action Control. The Action control performance of the PowerView featured single-handed access to all operations necessary for information retrieval. This was not the case for the Windows CE Action control performance.

3.2.4 Postures

Two posture conditions (Sitting and Standing) were presented, one biased towards two-handed interaction (stylus) and the other one biased towards single-handed interaction (Action control). For each interface, the subject first performed all tasks sitting at a table with the device lying in front of him. In the second condition, the subject was prompted to stand up (Standing condition) and hold a cordless phone in the non-preferred hand. The subject was then handed the Cassiopeia device and prompted to solve the tasks using the Action Control. In the case of PowerView, the subjects were reminded that all necessary information retrieval operations could be performed using the Action control.

3.2.5 Tasks

The subjects were exposed to seven information retrieval tasks on each interface. The tasks were identical in nature for both interfaces, and exactly the same data (emails, address entries, etc.) was used. Half of the subjects used the PowerView interface first, while the other half used Windows CE first. Subjects were told to complete the tasks without (if possible) any help and were timed on how long time it took to finish each task. If any help was needed to complete a task, this was considered as a failure. Subjects were not told whether the task was successfully completed or not.

The seven typical information retrieval tasks were presented in the following order:

1. Locate a scheduled meeting.
2. Find a person's phone number in the address book.
3. Locate specific details for a certain meeting.
4. Find and open a received mail.
5. Return to the Overview/Active Desktop.
6. Go to the task list and locate a remainder.
7. Find a certain date in the calendar and write down found details.

3.3 Dependent Variables

The dependent variables were both objective and subjective. Effectiveness was measured as number of successfully solved tasks. The subject had to complete the task correctly without asking for help in order to score.

Efficiency (the cognitive resources expended in relation to the accuracy and completeness of goals achieved) was measured in the form of task completion time. Completion time was measured from the moment the subject started reading the task instruction to the moment when the subject started to write down the answer or give the answer orally.

A simplified version of Mohageg´s “deviation from optimum path” measure (Goldstein *et al*. 1999, Mohageg 1992), using a binary approach (using Optimum path = 1, not using Optimum path = 0) was computed for each task. Optimum Path (Op) is defined as the shortest (navigation) route through a network of nodes to successfully solve a task. Deviations from Op may predict the experience of uncertainty during task performance.

A multidimensional workload assessment inventory, NASA-TLX was administered after each condition. Finally, subjects’ spatial ability was assessed.

3.4 Procedure

After a brief introduction, the subjects were seated at a table with the Cassiopeia E-11 lying on top of it. A short written description was presented to the subject: *"This is a PDA (Personal Digital Assistant). It can be seen as a digital Filofax with several applications like a Calendar, Mail, To Do list and an Address Book. It has a touch screen and you can use the ‘pen’ or use the ‘Action Control’ on the left side to navigate. It also has* *an Exit button with which you can 'Quit' an active 'application'*." The experimenter then showed where on the device the Action Control and the Exit button were located.

The subjects were then given six minutes to get familiar with the interface. After the familiarization time was over the interface was set to the Initial view (Overview for PowerView and Active Desktop for Window CE) and the seven tasks were presented in written form. Upon finishing the seven tasks, the subject performed seven tasks of similar type, this time standing and prompted to hold a cordless phone as well. The subjects were allowed to find their own way of holding the phone as long as they did not attach it on to themselves or put it away. The subjects were explicitly encouraged to use the Action control in this condition, since navigation (according to the designer's conceptual view) would be easier. The answer to each task was then given orally. Next, another completion of the workload inventory took place, followed by a final assessment of the particular interface. The whole procedure was then repeated for the other interface.

Finally, the subjects were requested to complete a spatial ability test within a fixed time limit of 12 minutes. The whole experiment was videotaped except for the completion of the questionnaires. The experiment time lasted between 60-90 minutes for each subject.

4. Results

4.1 Objective Findings

4.1.1 Accuracy

Accuracy (Effectiveness) was defined as the total number of correctly solved tasks. The main factor Interface was not significant while the main factor Posture was significant ($F[1,15]=14.613$, $p=0.002$). No interaction effect was observed. In the posture "Sitting" 85% of the 102 (16 x 7) tasks were solved using Windows CE whereas 95% of the tasks were solved using PowerView.

4.1.2 Task Completion Time

The main factor Interface was significant ($F[1, 9]=7.387$, $p=0.004$) regarding total task completion time (Efficiency). Due to previous learning to complete a task, subjects needed significantly shorter time the second time the tasks were performed, i.e. the Posture factor affected total retrieval time significantly. For all tasks except for task 6, task retrieval time was significantly shorter when performed the second time in the Standing posture than performed for the first time in the Sitting posture ($F[1,15]>5.503$, $p<0.033$). The interaction effect between Interface and Posture was not significant.

4.1.3 Choosing Optimum Path

The Optimum path (Op) performance measure was dichotomized. The subjects either used Op or they did not use it. The both main factors Interface and Posture were significant regarding the use of Op ($F[1,9]=5.716$, $p=0.009$, $F[1,9]=15.142$, $p<0.001$) whereas the interaction effect was not. Only for task 5 and task 7 did Op significantly differ between Interface types ($F[1,15]>7.979$, $p<0.013$). Whereas Op was significantly more frequently chosen for PowerView when completing task 5, it was significantly more frequently chosen using Windows CE when completing task 7.

For all tasks except for task 2 and task 6, Op was significantly more frequently chosen when in the Standing posture (the task was being performed the 2nd time) than when performed in the Sitting posture (the task was being performed for the first time) ($F[1,15]>5.87$, $p<0.029$).

Only for task 6 was the interaction between Interface and Posture significant ($F[1,15]=4.623$, $p=0.048$). Whereas frequency for choosing Op increased in PowerView for task 6 in the condition Standing, it decreased for Windows CE. For all other tasks, the frequency of choosing Op increased or remained unaffected when performing the task the second time.

4.2 Subjective Findings

4.2.1 The Workload Inventory

The NASA-TLX workload inventory was used as input in this Repeated-measurement analysis. The main factors Interface and Posture were not significant, nor the interaction effect. Neither the three demand factors nor the three level factors were significant across Interface types. Out of the six rated factors, only Effort level (measured in mm) was significant as a function of Posture ($F[1,15]=4.801$, $p=0.045$). Effort level was regarded as higher (sic) for the Sitting (53 mm) than for the Standing Posture (45 mm).

4.2.2 *Final Assessment of the Interface Types*

Only one of the eight different attributes, "Arrangement of information on the screen was helpful?", was rated significantly different ($F[1,15]=8.497$, $p=0.011$). The Windows CE interface was rated as significantly less helpful (6.25) than PowerView (7.40).

4.2.3 *Efficiency and Spatial Ability*

The subjects scored high on the spatial ability test. Eight had Stanine values of between 7 and 9 (classified as High) whereas the remaining eight scored between 1 and 6 (classified as Low). A repeated measurement analysis treating spatial ability (High/Low) as a between-subject factor and Efficiency (measured as total task completion time for each interface for the condition Sitting) as a within-subject factor gave no significant result regarding Interface or Spatial ability. The interaction effect between Interface and Spatial ability was not significant either. However, subjects scoring both Low and High on Spatial ability needed shorter time to complete the 7 tasks using PowerView than Windows CE (881 s vs. 1091 s for Low Spatial ability and 705 s vs. 916 s for High Spatial ability).

4.2.4 *The Action Control*

Although two-handed interaction using the stylus while holding the cordless phone and standing simultaneously was much more strenuous and cumbersome, the subjects systematically refrained from using the Action Control. Since the PowerView interface was deliberately designed to facilitate single-handed interaction, and the experimenter explicitly encouraged the subjects to try using the Action Control, this came as a surprise. Nine out of sixteen subjects did not even attempt to use single-handed navigation. The other subjects briefly used the action control and stated that they didn't want to use it. They felt it was unnecessary and uncomfortable or simply forgot to use it.

5. DISCUSSION

The usability of the Action Control was in fact not assessed in the experiment although usage was. Thus, (assumed good) usability may be a poor predictor of actual usage (Eason 1984). The most interesting finding was the extent to which users avoided using the Action Control. Below, we present strategies employed in order to be able to navigate with two hands. They serve as illustration of what discomfort subjects were prepared to accept in order to avoid single-handed navigation. We then present a number of possible reasons for this behavior.

5.1 Avoiding Single-handed Navigation

The most common strategies for avoiding single-handed navigation were to place the cordless phone under or beside the PDA. This made it possible to use two-handed stylus navigation and still follow the test instructions, i.e. not to put away the phone.

The most painstaking approach used was to put the cordless phone between the neck and the shoulder with the head tilted. The phone was held in this awkward way throughout the standing phases of the evaluation (2x15 minutes) (figure 6).

Figure 6. Arranged scene with subject holding the cordless phone by the neck.

5.2 Reasons for Avoiding Single-handed Navigation

5.2.1 *Experimental Design*

The subjects were first introduced to the interfaces in the sitting position where there was no bias against two-handed navigation. This may be a cause for the preference of two-handed navigation. However, since the subjects were prompted by the experimenter at three separate occasions to use the Action Control, in particular just before performing the tasks when one hand was occupied, this reason is unlikely be the main reason for the noticed behavior.

5.2.2 Ergonomics

Many subjects expressed that they felt uncomfortable controlling the PDA with one hand. Two subjects explained muscle strain as one reason. Most subjects held the PDA with the fingers close to the relevant buttons, but due to the width of the PDA it was difficult to securely hold the PDA and simultaneously manipulate it. Comparing the device with a mobile phone, which people manipulate using just one hand, the main difference is that the phone fits securely into the palm making it unnecessary to use the tip of the fingers to hold the device. The size of the Cassiopeia E-11 might be just a bit too wide to afford single-handed navigation.

5.2.3 Affordances of the PDA

More than just the size of the PDA may have inclined people to forget or refrain from using the Action control. Given the design and intended use, a PDA is very similar to a notebook, a time manager or a phonebook, all used with a pen. However, a notebook can be used without a pen if no scribbling is to be done. As the evaluation tasks only consisted in retrieving information it should have been possible to perform the tasks without a pen even on a notebook.

5.2.4 The Ease of Pointing

Norman (1991) has observed that any new translation between action and effect, in this case using the Action Control to navigate, adds cognitive overhead (Thüring, Hanneman and Haake 1995). Pointing is practiced since infancy and the use of a pen to point, write and draw seems to be a natural and powerful mode of interaction. The fact that subjects used the stylus can be an indication that it had the least cognitive overhead, and was thus preferred to the Action Control.

5.2.5 Einstellung

The phenomenon *Einstellung* has been described as: "If a person is trained to solve problems in a particular problem class with method A and he/she is presented with problems in that class which can be solved both with method A and method B, he/she tends to continue to use method A, even if B is simpler" (Ohlsson in Luchins and Luchins 1968, p.247, 1994). The phenomenon has also been described using the term *mechanization* (Baron 1994, Luchins and Luchins 1968), stating that subjects use a tried, trusted or familiar method even when a faster or better method is available. Applied to the evaluation, Einstellung might explain why the subjects, being unfamiliar with the device, lacked the flexibility to try using single-handed navigation.

5.3 Hardware vs. Software

The designers of the Action Control obviously intended to enable single-handed use of the Cassiopeia. The test subjects, however, did not seem to find the Action Control very usable. It seems that the relation between hardware and software is more intimate when designing interfaces for PDAs than for desktop PCs. In the latter case, the hardware is developed to support a person sitting at a table, which is what most often happens. A mobile user, on the other hand, encounters a number of different situations where the PDA will not be in focus to the same extent as the desktop PC is in the office. Our experiment, while only examining one such situation and still maintaining the PDA as the user's focus, shows how easy it is to find cases when users' behavior differs from what designers envisioned.

After having performed the experiment, it became clear to us that the design of a PDA, especially its controls, is important for how users experienced them. As input controls have to be taken into greater consideration, and these controls differs more between different PDAs than between different desktop PCs, the task of creating generic interfaces for PDAs poses greater challenges. This calls for a more integrated design of hardware and software of handheld devices, a point in line with the arguments made in favor for "information appliances" (Norman 1998). Further, earlier introduction of usability testing in both hardware and software design would give developers feedback of how the devices will actually be used.

6. CONCLUSIONS

The usability evaluation indicates that the prototype system, PowerView, was, with minor variations, equivalent in usability compared to the Windows CE application bundle. However, subjects did not use the added functionality of single-handed navigation that PowerView offered. Several possible reasons for this result have been discussed. The design of the PDA in terms of ergonomics and affordance might have directed the users towards two-handed navigation. Further, prior experience with other pointing devices might imply that the stylus input technique had the lowest cognitive overhead. Finally, Einstellung may have caused the subjects to overlook new interaction techniques to solve problems.

To further ratify the findings presented here, evaluations with other devices than the E-11, which allow for both single-handed and two-handed interaction should be performed. Also, evaluations of single-handed input interaction should be performed. The evaluation points to several issues regarding the design of PDAs. Allowing single-handed navigation on PDAs requires a trade-off between the control of the device and the size available for information display. Integrated design of both software and hardware is required to ensure that the intended usability of a device is reached in order to be able to predict successful usage.

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