Considerations on Efficient Touch Interfaces – How Display Size Influences the Performance in an Applied Pointing Task

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Abstract. The limited screen space in small technical devices imposes considerable usability challenges. On the one hand objects displayed on small screens should be big enough to be hit successfully, but also small enough to house several objects on the screen at the same time. However, findings up to now show that single pointing is more effective in a large display compared to a smaller display. In the present experiment this was also confirmed for an applied multidirectional serial pointing task. Especially in more difficult tasks, results point at a shift of the speed-accuracy tradeoff. In large displays a fast and comparably accurate execution is chosen in contrast to a very inaccurate and time-consuming style in small displays. From an ergonomic point of view the outcomes recommend an optimized balance of task difficulty and display size in small screen devices.

Keywords: Task difficulty, display size, pointing performance, small screen device, touch input.

1 Introduction

A broad user group increasingly uses mobile devices in business as well as private areas. The limited screen space in small technical devices imposes considerable usability challenges. On the one hand objects displayed on small screens should be big enough to be hit successfully, but also small enough to house several objects on the screen at the same time. Thus, the optimization of object size and display size is of crucial interest in modern device design. A standard research paradigm for the evaluation of the ergonomic design of hard- and software is given by Fitts' law [1]. It predicts movement time (MT) as a function of task difficulty (= ID, index of difficulty), determined by target distance (Amplitude) and target size (Width). The modification of the original law [1] by MacKenzie [2] is nowadays established in the ISO [3] with $MT = a + b \log_2 (A / W + 1)$. According to this function, bigger and nearer targets are easier to reach than smaller and farther away targets. A considerable

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amount of studies [e.g. 4-8] supported that the motor behavior operating an input device follows the same fundamental psychomotor principle as found for manual aiming movements. However, contrary to Fitts' law were findings of target size being of higher importance for the efficiency of aiming performance than target distance [5,6,9]. Sutter and Ziefle [5,6] showed that target size and target distance did not equally contribute to task difficulty as proposed by Fitts. But target size had a more powerful effect on movement time insofar that movement time was disproportional longer for smaller targets. Findings of Tränkle and Deutschmann [10] points at another restriction of Fitts' law as a design tool. The authors showed that pointing performance with a mouse was much more effective in a large display compared to a smaller display. Beyond the significant effect of task difficulty the impact of display size might be interpreted as a cognitive effect: The processing of larger space in which the movement has to be executed impose on a faster movement execution. Participants seemed to react more carefree and moved the mouse cursor much faster and snappier compared to the smaller display where movement space appeared more restricted. This was also observed for touch based interfaces operated with a stylus [11].

The discussion about task difficulty in modern applications might again be surveyed with this background in a more applied context. Displays in technical devices get smaller and smaller and their restricted movement space are contradictory to an efficient interaction. This study surveys an optimized design for touch interfaces in small screen devices with a stylus as input device and an applied pointing task. Data were analyzed according to two hypotheses: (1) The predicted effects of task difficulty on the basis of Fitts law [2] will be replicated ones more in this study. According to this, movement time should be prolonged in high task difficulties being composed of small target sizes and target distances being farther away. (2) The impact of display size and its interaction with task difficulty is considered. If assuming that display size acts as perceptual frame of reference, determining the speed of movement due to its ballistic nature or to cognitive effects, it can be deduced that larger display sizes should result in faster movements, accompanied by a lower accuracy of the pointing movement.

2 Method

The experiment was based on a two-factorial design with repeated measurements. The *independent variables* were the *display size* of the touch screen and the *difficulty of pointing task*.

Three display sizes were realized, covering a wide range of screen sizes present in real devices equipped with a touch interface (Figure 1; Display 1 = 6.00 x 8.00 cm, Display 2 = 12.00 x 16.00 cm and Display 3 = 18.00 x 24.00 cm). Difficulty of the pointing task was varied from 1.81 to 4.95 bits [2]. In dependence on display size, in maximum four target sizes (0.25; 0.50; 0.75 and 1.00 cm) and three target distances (2.50; 5.00 and 7.50 cm) were chosen. Due to the three different screen sizes and the spatial restrictions of the smallest display, respectively, the IDs to be realized differed across the display sizes. There were two IDs realized in all three display sizes, ID 2.58 bits and ID 3.46 bits. Thus, the research question at issue, the influence of display size on performance in an applied pointing task can be analyzed for these two IDs. Both IDs represent typical task difficulties for mobile devices. Exploiting the increasing display space with respect to the analysis of more IDs, five different IDs were realized for the medium display size (2.12; 2.58; 2.94; 3.46; 4.39 bits) and in total nine IDs were possible to be realized for the large display size (1.81; 2.12; 2.58; 2.94; 3.09; 3.46; 4.00; 4.39; 4.95 bits).

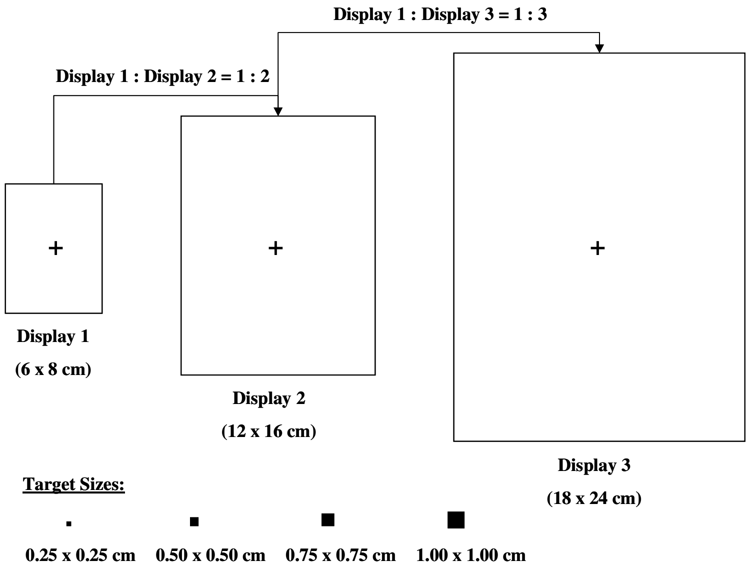

Fig. 1. Schematic illustration of display size and target size

Sixteen participants (N = 16) accomplished each 86 serial multidirectional pointing tasks on a high precision touch screen with a stylus. In each task, a sequence of nine square targets was presented directly one after another and users had to move the pen from a well-defined starting point inside the target area. Participants had to work on all display sizes and on all task difficulties (IDs). The order of display sizes was balanced over participants. The order of IDs within each display size was at random. To exclude confounding effects of movement direction and to realize the applied multidirectional pointing task, the target position was placed in eight different directions (0°, 45º, 90º, 135º, 180º, 225º, 270º, 315º) relative to the starting point of movement [3]. Time and spatial information of pointing movements (x-, y-coordinates) were recorded action-correlated with a logging and analyzing software tool [11]. A state of the art high precision 15'' (diagonal measurement) TFT touch screen (Iiyama AX 3819 UT) with a 1024 x 768 resolution and a "Touchlogic Twisted Nematic®" (RS 232C ELO Touchsystems) was used. The three different display sizes on the touch screen were created by the software program and represented simply a lighted area with the rest of the display kept dark and inactive. The stylus was a high precision professional touch input device for industrial applications (WES®).

Dependent variables were on the one hand time and accuracy of pointing as objective measures and on the other hand usability ratings in terms of task difficulty and their effort to complete the serial multidirectional pointing task.

The *time* measure of performance included the movement time to complete a whole task, which described the interval of time from correct pointing with the stylus on the onset point to final correct pointing on the last of all nine targets. For *accuracy*, the incorrect pointing was logged, defined as pointing error. This error occurred when participants did not hit the target itself, but pointed outside the target's boundaries.

Usability ratings were measured by *participants' judgments of task difficulty and effort* on a 4-point scale in a questionnaire (1 = low; 2 = reasonably low; 3 = reasonably high; 4 = high). In order to facilitate ratings for participants, the actual task difficulties (IDs) composed of target sizes and distances were operationalized in either smaller or bigger targets for each display size. In doing so, the smaller targets comprised the higher IDs whereas the bigger targets comprised the lower IDs.

3 Results

3.1 Effects of Task Difficulty

According to Fitts' law a regression analysis comprising all realized task difficulties (IDs) across the three display sizes revealed a high positive correlation (r = .82; $p < 0.001$; R^2 = .77) between task difficulty and movement time. Additionally, a high positive correlation (r = .83; $p < 0.001$; R^2 = .72) between task difficulty and pointing errors could be found.

Analyzing only the both IDs (2.58 and 3.46 bits) present in all three display sizes an analyses of variance (ANOVA) for repeated measurements showed the validity of Fitts' law for movement time in pointing tasks on all three display sizes (F (1,14) = 67.30; $p < 0.001$). Movement time increased significantly with increasing task difficulties (Figure 2). Again, a strong effect of task difficulty on pointing errors could be found (F (1,14) = 71.17; $p < 0.001$), i.e. the higher ID of 3.46 bits induced significantly more pointing errors than the lower ID of 2.58 bits (Figure 3).

Usability ratings of task difficulty and effort confirmed the described findings in pointing time and accuracy across all display sizes. For the subjective difficulty of smaller and bigger targets per display size, a non-parametric Friedman-Test revealed significant ranks ($\chi^2_{(5)}$ = 71.51; $p < 0.001$). Generally, the smaller targets of each display size, which comprised actually the higer IDs, were rated as fairly "reasonably high = 3 of 4" in difficulty (small display: M = 2.81; medium display: M = 2.69; large display: M = 3.13). The smaller targets on the large display were significantly rated as most difficult of all realized targets, even compared with a non-parametric Wilcoxon-Test to the next difficult targets on the medium display (Z = -2.11; $p < 0.05$) and on the small display (Z = -1.89; p = 0.059). Amongst them, the objective most difficult pointing task of the whole study with an ID of 4.95 bits was present, but on the other both display sizes not. This finding confirms the quality of participants' usability ratings. Additionally, this is corroborated by participants' difficulty ratings of the bigger targets (lower IDs) on the three display sizes as fairly "low = 1 of 4" (small display: M = 1.25; medium display: M = 1.25; large display: M = 1.38). Comparing the average difficulty ratings for the higher IDs (M = 2.88) and lower IDs (M = 1.29) significant differences in ratings (Z = -3.54; $p < 0.001$) could be found.

A similar pattern appeared for the estimated task effort of smaller and bigger targets per display size. The non-parametric Friedman-Test revealed likewise significant ranks ($\chi^2_{(5)} = 62.78$; $p < 0.001$). The smaller targets of each display size were rated as fairly "reasonably high = 3 of 4" in effort (small display: $M = 2.69$; medium display: $M = 2.81$; large display: $M = 3.13$). Here again, the smaller targets on the large display were rated to be of highest effort. Participants rated the pointing effort of the bigger targets (lower IDs) on the three display sizes as fairly "low = 1 of 4" or "reasonably low = 2 of 4" (small display: $M = 1.50$; medium display: $M = 1.50$; large display: $M = 1.81$). Comparing the average effort ratings for the higher IDs ($M = 2.88$) and lower IDs ($M = 1.60$) a non-parametric Wilcoxon-Test showed significant differences in ratings ($Z = -3.54$; $p < 0.001$) just as well as for the usability ratings of task difficulty.

3.2 Effects of Display Size

The data for those both IDs (2.58 and 3.46 bits) present in all three display sizes were analyzed by analyses of variance (ANOVA) for repeated measurements. According to our second hypothesis a significant interaction between display size and task difficulty for pointing time (F (2,13) = 7.81; $p < 0.01$) and pointing errors (F (2,13) = 10.42; $p < 0.005$) could be found. From an ergonomic point of view this interaction is insightful, as it shows that the very same task difficulty can result in a different performance depending on how large or how small the display is.

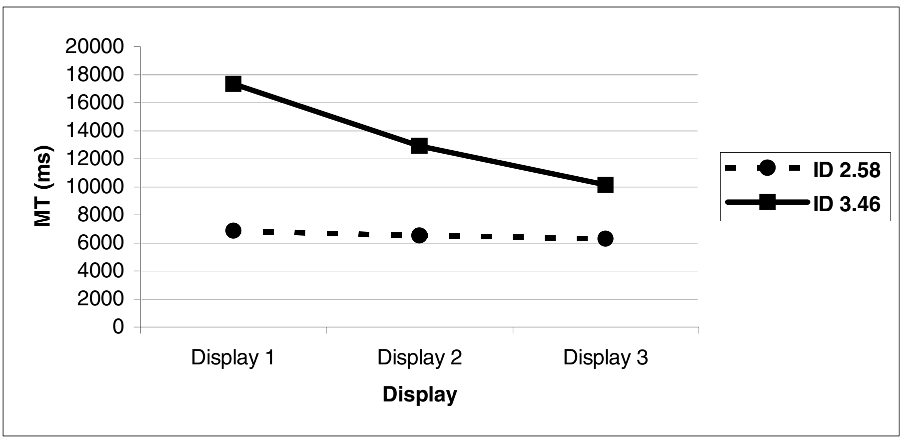

Fig. 2. Interaction effect for the display size (small = display 1; medium = display 2; large = display 3) and ID (2.58 and 3.46 bits): movement time (ms)

If ID is low (2.58 bits) pointing time was reduced clearly the larger the display size was (small display: $M = 6867.26$ ms; medium display: $M = 6531.67$ ms; large display: $M = 6295.44$ ms). The large display provided an observable gain of about 8% in pointing time compared to the same task difficulty in the small display. In direct contrast, for higher IDs (3.46 bits), pointing time has significantly increased for the small display ($M = 17326.16$ ms) when compared to the medium ($M = 12926.39$ ms)

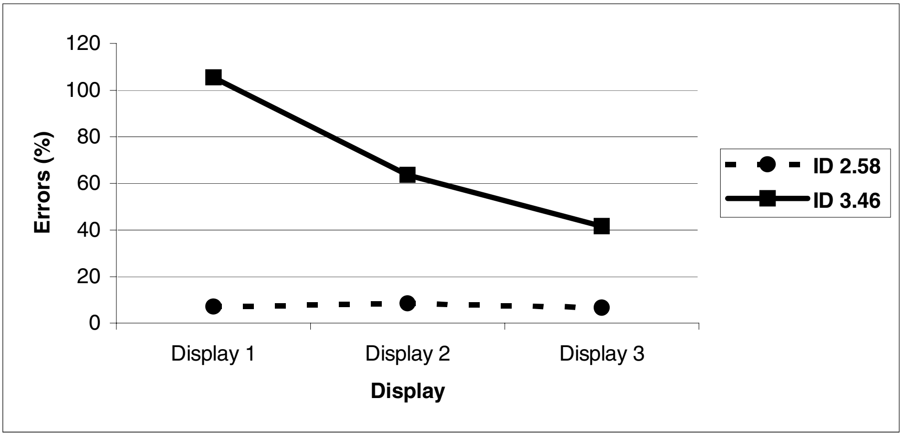

Fig. 3. Interaction effect for the display size (small = display 1; medium = display 2; large = display 3) and ID (2.58 and 3.46 bits): pointing error (%)

and large display (*M* = 10145.94 ms). The disadvantage of having a small display and a high task difficulty (ID of 3.46 bits) ranged at 41 % compared with the same task difficulty on the large display. This interaction is illustrated in Figure 2.

A similar pattern was found for pointing accuracy (Figure 3). While the percentage of errors did not differ due to display size for the lower ID 2.58 bits (small display: *M* = 7.11%; medium display: *M* = 8.56%; large display: *M* = 6.67%), a remarkable higher number of errors were revealed for the higher ID 3.46 bits depending on the display size: The lowest amount of pointing errors was found in the large display (*M* = 41.55%). It increased already for the medium display (*M* = 63.44 %) and mounted up to an error peak of 105.44% for the small display. An error rate of more than 100% means that more than nine errors occurred in the respective serial multidirectional pointing task. In this case, participants executed, on average, 1.05 errors per target until the whole serial pointing task of nine consecutive targets in the small display was finished properly.

A moderating influence of display size on participants' usability ratings like on the objective measures (pointing time and errors) could not be found.

4 Conclusions

The design of efficient touch interfaces is becoming a challenge in ergonomics. Displays in technical devices get smaller and smaller and their restricted movement space are contradictory to an efficient interaction. In literature the impact of display size on motor performance in combination with an increase of task difficulty in smaller displays is reported [10,11]. These results are theoretical unexpected, but can be interpreted in a cognitive or motor behavioral way [11]. Nevertheless, the practical implications are manifold towards the design of small screen interfaces.

The findings of the present experiment once more confirmed Fitts' law for pointing movements executed with a stylus. An increase of task difficulty in the applied multidirectional serial pointing task resulted in a lower pointing performance, i.e. movement time and pointing errors rose distinctly. These results stand in concordance with many other studies regarding input device performance in dependence on Fitts' law [e.g. 4-8]. Moreover, whenever in the present experiment the task execution was complicated users clearly stated their higher effort and difficulty of solving the pointing task properly.

The impact of display size and its interaction with task difficulty was considered with reference to two aspects. First, from a theoretical point of view this result is rather surprising. So far, the interaction between display size and task difficulty was found under strict experimental conditions [10,11]. When one rapid aimed movement had to be executed to solve a simple point-click task then pointing performance was much more effective in a large display compared to a smaller display. This was also confirmed in the present study with an applied multidirectional serial pointing task. The interaction was, until now, interpreted in the meaning of the perceived frame of reference, which allows a freehanded movement execution in larger spaces. However, the present results hint at different strategies of motor behavior. Especially regarding the more difficult pointing tasks (higher IDs), in large displays the speed-accuracy tradeoff [12] is shifted towards a fast and comparably accurate execution whereas in small screens a very inaccurate and time-consuming style is chosen. Thus, the cognitive processing of the frame of reference is very likely to affect the speed-accuracy tradeoff. However, this has to be addressed systematically in further research. Second, from an ergonomic point of view the interaction between display size and task difficulty is insightful. It shows that the very same task difficulty can result in a different performance depending on how large or how small the display is. The outcomes of this research allow ergonomic guidelines for an optimized usage and design of touch-based screen devices, assuring efficient and effective handling. It is therefore important to achieve an optimized balance of task difficulty and display size in small screen devices. That means that targets in small displays should be in easy reach for an effective interaction.

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