Usability of the Stylus Pen for Various Age Groups

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Abstract. This paper investigates the age factor on the usability of pens when using PDAs. Older users and child users were asked to perform the experiments in which they conducted pointing and steering tasks on a PDA using various sizes of pen. Six combinations of pen length, width and pen-tip width were compared in the test. Five pen-lengths (7, 9, 11, 13, 15 cm), three pen-tip widths (0.5, 1.0 and 1.5mm) and the two pen widths (4 and 7mm) were compared. The results show that the most suitable pen dimensions for older users are 11-15cm for length, 1.0-1.5mm for tip width, and 7.0mm for pen width; and for child users the length is 7-13cm, tip width is 1.0-1.5mm, and 4.0mm is the optimum pen width.

1 Introduction

With handheld information devices such as personal digital assistants (PDAs), users are often required to interact with a number of objects on a small display. Pen input, which has already been adopted in most current PDAs, is considered to be an efficient input method which permits direct and intuitive manipulation. There have been many studies on PDA interfaces, e.g. [3][7]. However, there have been few studies which examine the effects of the size of the stylus pen on user performance and subjective preferences for PDAs interfaces.

To maximize the usability of these devices, serious consideration must be given to the physical aspects of the pen, such as its length, width and tip-width. Therefore, we studied the most suitable length, tip-width and width for a pen [8]. However, the experimental subjects were only young-adult users. The optimal size for the other age was still not clear. In this paper, we consider the age issue in connection with the usability of input pens when using handheld devices.

User interface designers often have to conduct empirical comparisons among many candidate devices. In order to measure the user performance during completion of simple tasks, Fitts [4] carried out an experiment to establish a model for movement time in pointing type tasks, known as Fitts' law, commonly expressed in the following equation [5]:

$$MT = a + b \log_2 (\frac{A}{W} + 1) \quad (1)$$

where *MT* is the acquisition time of a pointing task, *A* is the distance or amplitude from the starting position to the target, *W* is the width of the target, and *a* and *b* are empirically determined constants; the reciprocal of *b*, called the index of performance (*IP*), is often used as a measure of input device efficiency. The log term of the equation is defined as the index of difficulty for a pointing task (ID_P).

$$ID_P = \log_2(\frac{A}{W} + 1) \quad (2)$$

Modern computer interactions, however, are more than just pointing tasks. One limitation of Fitts' law paradigm is that it can be applied for pointing tasks and cannot be applied for other tasks such as drawing, writing and navigating through a menu and its nested menus. Accot and Zhai [1] provided the first quantitative tool for predicting the difficulty of HCI steering tasks. A steering task requires one to move the input device (or pointer of the device) a certain distance through a tunnel. A daily example of the steering task is driving an automobile without crossing the road boundaries [2]. Examples of the steering task performed with input devices include steering through a menu and moving the scroll bar of a window. Accot and Zhai called the following model a "steering law" which models the relationship between completion time *MT* and task parameters:

$$MT_S = a + bID_S \quad (3)$$

where *a* and *b* are empirically determined constants, 1/*b* is called the index of performance (*IP*) in a steering law. *IDs* is the index of difficulty of the steering task which, for linear movement, is defined as:

$$ID_S = \frac{A}{W_S} \quad (4)$$

where *A* represents tunnel length, *Ws* represents tunnel width. For circular tunnel movement, *IDs* can be defined as:

$$ID_S = \frac{2p\ r}{W_S} \quad (5)$$

where *r* is the radius of the circle and *Ws* is the width of the tunnel.

We can use the steering model as a quantitative measure for determining the performance of candidate devices in our experiments. We hypothesized that the significance (or insignificance) of the differences between the candidate pens may be adequately observed in each of the two tasks (pointing and steering).

2 Method

2.1 Subjects

In the experiment for older users, we employed twenty-four subjects so that fatigue for each subject could be minimized. Twelve subjects (7 male and 5 female) participated

the experiments in which pen-length was tested. Subject ages ranged between 60 and 71 years. The average age was 62.25. Another twelve subjects (7 male and 5 female) participated in the experiments in which tip-width and pen-width were tested. Subject ages ranged between 60 and 79 years. The average age was 71 years. All subjects were right-handed. None of the subjects had previous experience using PDAs.

In the experiment for child users, twelve subjects (8 male and 4 female) participated. Subject ages ranged between 10 and 11 years. The average age was 10.75. None of the subjects had previous experience using PDAs.

Each subject held the PDA with their non-dominant hand and the input device with their dominant hand while in a sitting posture. All subjects were instructed not to rest their hands (elbow or arms) on the table or any other objects during the experiment. This ensured that the environment was common to each user and that it was also a typical and universally available PDA environment.

2.2 Apparatus

In the experiments, the device used was an "iPAQ Pocket PC" by Compaq Co., running Windows CE 3.0. The size was 84mm (W) x 16mm (D) x 134mm (H). It weighed 184g. It had a 240 x 320 pixel display with a 0.24 mm pixel pitch. The display was accurately calibrated before the experiments. The experimental programs were developed using Sun Microsystems JAVA (for the pointing task and the steering task).

2.3 Pen-length, pen-tip width and pen-width

We tested the effects of pen-length using five lengths (7, 9, 11, 13, 15cm) all with 1.0 mm pen-tip width and 6 mm pen-width in Pen-length Experiments for both older users and child users. A pilot study showed that any pen length less than 7 cm was too difficult to handle [6]. Regarding the longest pen tested, 15cm is approximately the same length as an ordinary pencil or a ball point pen with a cap.

In the Tip-width/pen-width Experiment, we set two pen-widths (4mm and 7mm) and three pen-tip widths (0.5mm, 1.0mm and 1.5mm) as the independent variables range. The reason we chose these settings was that the pen-width attached to existing PDAs was close to 4mm or 7mm and they are close to the pen-width of a real pen and pencil. We combined the three pen-tip widths (0.5, 1.0 and 1.5mm) and the two pen-widths (4 and 7mm) giving us six pen-tip widths/pen-widths combinations, i.e. 0.5mm/4mm, 1.0mm/4mm, 1.5mm/4mm, 0.5mm/7mm, 1.0mm/7mm, 1.5mm/7mm pens (pen-tip width/pen-width).

All experiments included the two tasks described in detail in the following sections.

2.4 Pointing task

The steps for pointing at a target were as follows:

(1) *The center circle was displayed*: In the beginning of this task, the white circle (the center circle) was displayed in the center of the PDA display. Subjects tapped the center circle. When the center circle was tapped, the start time was recorded.

(2) *The target was displayed*: The center circle turned black when the subject tapped it, and the other white circle (target) was displayed randomly on the PDA display. The subject was asked to tap the target as quickly and accurately as possible. When the target was tapped, the end time was recorded, and, if the target had not been tapped accurately, an error was recorded.

(3) *Repeat*: The white center circle was displayed again immediately after the subject tapped the target. The subject repeated (1) and (2).

After they finished testing each pen, the subjects were asked to answer a questionnaire which included: ease of pointing, degree of fatigue, and a overall evaluation on a scale from 1 (worst) to 7 (best).

The factorial design and levels were as follows:

- The target appearance positions were located in 8-directions around the center circle.
- The distances between the center of the center circle and the center of the target were 50 and 100 pixels.
- The diameters of the targets were 10, 20 and 30 pixels.

After the procedure for the task was explained to the subject, a practice session with the accessory pen was performed. After this, the subjects were told to do the real trials. For each of the eleven pens (five pen-lengths + six pen-tip widths/pen-widths), each subject had a total of 48 test trials (8 directions x 2 distances x 3 target sizes). Each subject completed 240 test trials (Pen-length Experiment) and 288 test trials (Tip-width/pen-width Experiment). For each pen, 576 test trials (12 subjects x 48 test trials) were completed. The order for all pens was different for each of the subjects.

2.5 Steering task

Two types of steering task, a straight tunnel and a circular tunnel, were used in the experiment. The steps for the steering tasks were as follows:

(1) *The tunnel was displayed*: In the beginning of this task, the tunnel (either linear or circular) was displayed on the PDA display. This is the path that subjects had to drag the pen-tip along.

(2) *Start segment and goal segment*: In each tunnel, there were the start segment and goal segment. In the linear tunnel, the frame of the start segment was black, and the frame of the goal segment was red. In the circular tunnel, the start segment and goal segment were located in the same position. When the subjects put the pen on the start segment, the label “START” was displayed in the upper left of the display as a signal to begin the task, and the start time was recorded. When the pen entered the goal segment, all objects on the display disappeared as a signal to end

the trial, and the end time was recorded. After that, the next trial was displayed. Releasing the stylus pen from the display after leaving the start segment and before entering the goal segment, or crossing the borders of the path, resulted in an "error" and the trial would be recorded as the invalid trial. The subjects were asked to continue to attempt the task until they succeeded in each trial.

The factorial design and levels were as follows:

- The task types were linear and circular.
- Distances were 50 and 100 pixels in the linear task, and 300 and 600 pixels in the circular task.
- Tunnel widths were 16, 24 pixels.
- Directions were left to right and right to left.

After the procedure of the task was explained to the subjects and a practice session with the accessory pen was performed. The subjects were then told to do the real trials. For each of the eleven pens (five pen-lengths + six pen-tip widths/pen-widths), each subject had a total of 16 test trials (2 task types x 2 distances x 2 widths x 2 directions). Each subject completed 80 test trials (Pen-length Experiment) and 96 test trials (Tip width/pen-width Experiment). For each pen, 192 test trials (12 subjects x 16 test trials) were completed. The order for the pens was different for each of the subjects.

After the steering task was completed, we asked the subjects to rate ease of dragging, degree of fatigue, and also to give an overall evaluation on a scale from 1 (worst) to 7 (best).

3 Results for older user group

The means were calculated for each of the evaluation indexes.

3.1 Pen-length

Pointing task. The results of an ANOVA did not reveal significant differences in either pointing time or error rate between the five pen-lengths. Mean pointing times for the 7, 9, 11, 13, and 15cm pens were 840.15, 862.89, 852.48, 823.25, and 829.64 milliseconds, and error rates were 10.07%, 11.46%, 10.94%, 7.99%, and 7.81% respectively.

Linear regression between pointing time and index of difficulty produced the following equations for each pen:

- 7cm pen: MT = 162.26*ID + 462.37 (R^2 = 0.99)
- 9cm: MT = 156.94*ID + 497.48 (0.94)
- 11cm: MT = 171.57*ID + 453.02 (0.98)
- 13cm: MT = 139.54*ID + 498.36 (0.98)
- 15cm: MT = 153.15*ID + 473.05 (0.95)

We computed the index of performance IP = 1/b that indicates pointing time increase as a function of task difficulty. The five pen-lengths tested in the experiment ranked in

the following order in pointing task: 13cm (IP = 7.17 s^{-1}), the 15cm (6.53), 9cm (6.37), 7cm (6.16), 11cm (5.83).

We analyzed the average value of the answers given by the subjects to three questions. The 11 cm pen received high ratings for the pointing task, $F(4,55) = 4.27$, $p < 0.05$ for the pointing task (mean = 5.25).

Steering task. There were no significant differences in either movement time or error rate between the five pen-length, in either linear or circular tasks. For the linear task, mean steering times for the 7, 9, 11, 13, and 15cm pens were 477.34, 443.31, 445.0, 435.58 and 418.26 milliseconds, and error rates were 8.29%, 5.93%, 5.93%, 4.44% and 6.53% respectively; for the circular task, mean steering times for the 7, 9, 11, 13, and 15cm pens were 1842.67, 1729.49, 1728.37, 1801.0, 1637.73 ms, and error rates were 21.58%, 20.09%, 16.68%, 14.93%, and 15.66% respectively.

By analogy to Fitts' law, steering law allows us to compute an index of performance IP = 1/b that indicates steering time increase as a function of task difficulty. The five pen-lengths tested in the experiment ranked in the following order in the linear steering task: 15cm (IP = 10.3 s^{-1}), 9cm (9.76), 13cm (9.74), 11cm (9.24), 7cm (8.15). For the circular task, the order was slightly different: 15 cm (8.33), 9 cm (8.23), 13cm (8.12), 11cm (8.07), 7cm (7.98).

The 11 cm pen received high ratings for the steering task, $F(4,55) = 8.69$, $p < 0.001$ for the pointing task (mean = 5.75).

Discussion. According to the experimental results, there was no significant difference in movement time or error rates in any of the three tasks, however, the IP values showed that the 13 cm pen was better than the other pens in the pointing task; the 15 cm pen was better than the other pens in the steering task. Moreover, the subjective evaluations showed that pens more than 11cm in length received high scores.

Taking these results and considerations together, pen lengths from 11-15cm can be regarded as the best choice for use on a PDA.

3.2 Tip-width/Pen-width

Pointing task. With regard to tip width and pen width, there were no significant differences between the six pens, i.e., 0.5mm/4mm, 1.0mm/4mm, 1.5mm/4mm, 0.5mm/7mm, 1.0mm/7mm, 1.5mm/7mm pens (pen-tip width/pen-width) in both pointing time and error rate. The mean pointing time for the 0.5mm/4mm, 1.0mm/4mm, 1.5mm/4mm, 0.5mm/7mm, 1.0mm/7mm, 1.5mm/7mm pens (pen-tip width/pen-width) were 1050.122, 1059.215, 999.550, 1012.08, 1001.12, 970.201 ms respectively, error rates were 10.94%, 12.67%, 11.28%, 8.51%, 11.28%, 10.24% respectively.

The six pens tested in the experiment ranked in the following order in the pointing task: 1.0mm/7mm (IP = 5.36 s^{-1}), 1.5mm/4mm (4.52), 0.5mm/4.0mm (4.02), 1.5mm/7.0mm (3.86), 0.5mm/7.0mm (3.27), 1.0mm/4.0mm (2.48).

No significant difference was found between the five pens in subjective ratings.

Steering task. There were no significant differences in either movement time or error rate between the six kinds of pen-tip width/pen-width, in either linear or circular tasks. For the linear task, mean steering times for the 0.5mm/4mm, 1.0mm/4mm, 1.5mm/4mm, 0.5mm/7mm, 1.0mm/7mm, and 1.5mm/7mm pens were 1654.81, 1566.94, 1617.14, 1539.98, 1544.667, and 1504.01 ms, and error rates were 14.96%, 11.16%, 14.42%, 12.89%, 1.85% and 8.94% respectively; for the circular task, mean steering times for 0.5mm/4mm, 1.0mm/4mm, 1.5mm/4mm, 0.5mm/7mm, 1.0mm/7mm, 1.5mm/7mm pens were 6169.40, 5859.80, 5836.94, 5787.60, 5708.90, and 5706.09 milliseconds, and error rates were 20.71%, 26.64%, 20.64%, 19.48%, 20.85%, and 25.90% respectively.

The six pens tested in the experiment ranked in the following order in the linear steering task: 1.5mm/7mm (IP = 6.49 s^{-1}), 0.5mm/7mm (5.91), 1.0mm/7mm (5.90), 1.5mm/4mm (5.75), 1.0mm/4mm (5.69), 0.5mm/4mm (4.95). For the circular task, the order was different: 1.5mm/7mm (5.24), 1.0mm/7mm (5.09), 1.0mm/4mm (4.71), 0.5mm/4mm (4.62), 1.5mm/4mm (4.59), 0.5mm/7mm (4.52).

No significant difference was found between the six pens in subjective ratings.

Discussion. According to the experimental results, there was no significant difference in movement time or error rate in the pointing tasks. However, the IP values showed that 1.0mm/7mm pens was better than the others in the pointing task, and 1.5mm/7mm pen was better than the others in the steering task.

Taking these results together, a pen-tip width from 1.0-1.5 mm and a pen-width of 7 mm can be regarded as the best choice for use with a PDA.

4 Results for child user group

The means were calculated for each of the evaluation indexes.

4.1 Pen-length

Pointing task. The results of an ANOVA did not reveal significant differences in either pointing time or error rate between the five pen-lengths. Mean pointing times for the 7, 9, 11, 13, and 15cm pens were 737.67, 738.31, 718.85, 719.04, and 719.23 milliseconds, and error rates were 17.53%, 22.05%, 16.67%, 17.71%, and 15.45% respectively.

We computed the index of performance IP = 1/b that indicates pointing time increase as a function of task difficulty. The five pen-lengths tested in the experiment ranked in the following order in pointing task: 13cm (IP = 7.30 s^{-1}), 15cm (7.22), 9cm (7.10), 7cm (7.06), 11cm (6.53).

We also analyzed the average value of the answers given by the subjects to three questions. The 11 cm and 13 cm pen received high ratings for the pointing task, $F(4,55) = 3.08$, $p < 0.05$ for the pointing task (mean = 5.25).

Steering task. There were no significant differences in either movement time or error rate between the five kinds of pen-length, in either linear or circular tasks. For the linear task, mean steering times for the 7, 9, 11, 13, and 15cm pens were 860.58, 808.67, 982.67, 771.5 and 830.75 milliseconds, and error rates were 13.63%, 10.05%, 8.57%, 13.43%, and 13.13% respectively; for the circular task, mean steering times for the 7, 9, 11, 13, and 15cm pens were 3478.33, 3304.83, 3381.33, 3165.0 and 3577.33 ms, and error rates were 32.06%, 35.02%, 25.22%, 37.62%, and 29.99% respectively.

By analogy to Fitts' law, steering law allows us to compute an index of performance IP = 1/b that indicates steering time increase as a function of task difficulty. The five pen-lengths tested in the experiment ranked in the following order in the linear steering task: 7cm (IP = 11.77 s^{-1}), 15cm (9.07), 13cm (9.04), 11cm (8.74), and 9cm (7.81). For the circular task, the order was slightly different: 7cm (7.08), 11 cm (7.03), 9cm (6.70), 13cm (6.60), and 15cm (5.59).

No significant difference was found between the five pens in subjective ratings.

Discussion. According to the experimental results, there was no significant difference in movement time or error rate in any of the tasks, however, the IP values showed that the 13 cm pen was better than the other pens in the pointing task; the 7 cm pen was better than the other pens in the steering task. Moreover, the subjective evaluations showed that the pens 11cm -13 cm in length received high scores.

Taking these results and considerations together, a length of 7-13cm pens can be regarded as the best choice for use with a PDA.

4.2 Tip-width/Pen-width

Pointing task. There were no significant differences between the six pens, i.e., 0.5mm/4mm, 1.0mm/4mm, 1.5mm/4mm, 0.5mm/7mm, 1.0mm/7mm, 1.5mm/7mm pens (pen-tip width/pen-width) in both pointing time and error rate. The mean pointing time for the 0.5mm/4mm, 1.0mm/4mm, 1.5mm/4mm, 0.5mm/7mm, 1.0mm/7mm, 1.5mm/7mm pens (pen-tip width/pen-width) were 718.40, 695.37, 711.89, 703.41, 698.02, 704.02 ms respectively, error rates were 14.58%, 15.28%, 12.15%, 14.06%, 13.19%, 12.5% respectively.

The six pens tested in the experiment ranked in the following order in the pointing task: 1.5mm/4mm (IP = 9.0 s^{-1}), 1.0mm/4mm (8.25), 0.5mm/7.0mm (8.18), 1.5mm/7.0mm (7.85), 0.5mm/4.0mm (7.04), and 1.0mm/7.0mm (6.30).

No significant difference was found between the six pens in subjective ratings.

Steering task. There were no significant differences in either movement time or error rate between the six kinds of pen-width/pen-width, in either linear or circular tasks. For the linear task, mean steering times for the 0.5mm/4mm, 1.0mm/4mm, 1.5mm/4mm, 0.5mm/7mm, 1.0mm/7mm, 1.5mm/7mm pens (pen-tip width/pen-width) were 708.0, 798.92, 731.25, 718.83, 673.33 and 647.17 milliseconds, and error rates were 17.85%, 8.38%, 16.16%, 9.31%, 17.33% and 10.66% respectively; for the circular task, mean steering times for the 0.5mm/4mm, 1.0mm/4mm, 1.5mm/4mm, 0.5mm/7mm, 1.0mm/7mm, and

1.5mm/7.0mm pens were 3169.92, 3388.25, 3171.08, 3210.08, 3340.08, and 3169.42 ms and error rates were 38.25%, 35.24%, 35.13%, 31.62%, 35.74% and 26.20% respectively.

By analogy to Fitts' law, the steering law allows us to compute an index of performance IP = 1/b that indicates steering time increases as a function of task difficulty. The six pens tested in the experiment ranked in the following order in the linear steering task: 1.0/4.0mm (IP = 17.11 s^{-1}), 1.5/4.0mm (12.32), 1.0/7.0mm (11.73), 1.5/7.0mm (9.95), 0.5/7.0mm (9.82), 0.5/4.0mm (8.92). For the circular task, the order was slightly different: 1.0/4.0mm (8.95), 1.5/4.0mm (7.65), 0.5/7.0mm (7.25), 0.5/4.0mm (6.60), 1.5/7.0mm (6.46), 1.0/7.0mm (5.89).

No significant difference was found between the six pens in subjective ratings.

Discussion. According to the experimental results, there was no significant difference in movement time or error rate for each of the tasks. However, the IP values showed that the 1.5mm/4.0mm pen was better than the others for the pointing tasks, and 1.0mm/4.0mm pen was better than the others in the steering tasks.

Taking these results together, a pen-tip width of 1.0-1.5 mm and a pen-width of 4 mm can be regarded as the best choice for use with a PDA.

4 Conclusions

This study investigated the effects of pen size on older users performance and child users performance through experiments based on the pointing and steering tasks.

The results of the experiments show that the dimensions of the pen affect user performance only a little but they affect user preferences quite significantly. There were no significant differences in performance with regard to pen size in most comparisons. This is due to the fact that the various dimensions of the pens designed by us only covered a small range, but the *IP* values and the subjective evaluations provided useful information which user interface designers can refer to for PDA pen design. We determined that the most suitable dimensions are as follows: pen length 11-15cm, pen-tip width 1.0-1.5mm, and pen width 7mm for older users; and for child users, pen length 7-13cm, pen-tip width 1.0--1.5mm, and pen width 4mm.

In our previous experiments for young users, we determined that the most suitable pen dimensions were 11 cm for length, 0.5 cm for tip width, and 7mm for pen width. Comparison of the three groups, we can see the following trend: the pen-length that older users use is longer than that young users use; and that child users may wish to use a shorter pen than that preferred by young adults and older users. Both young adult users and older users prefer the 7.0 mm pen while child users prefer the 4.0 mm pen. Both older users and child users prefer the 1.0-1.5 mm pens while young adult prefer to use the 0.5 mm pen. We summarized these sizes in Table 1.

We believe the findings of this study provide a base point for further research in this field with a view to the development of more useful pens. They will further enable designers to design stylus pens for handheld devices which will offer users greater comfort and greater efficiency.

Table 1: the most suitable pen dimensions for the three age groups

	Pen length	Pen width	Pen tip width
Older users (60+)	11-15cm	7.0mm	1.0-1.5mm
Young Adults (early 20s)	11cm	7.0mm	0.5mm
Children (10-11)	7-13cm	4.0mm	1.0-1.5mm

There are many challenges for future study to make this kind of research complete. Experiments under other conditions should be conducted. We would like to emphasize that the conclusions on the sizes (length, width, tip-width) of the pen were based upon the pens which we designed. We expect different conclusions once the designers test different variables of the pen, such as pen shape (round, hexagonal etc.). These will have a valuable impact on studies regarding the physical aspects of the pen.

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