The Optimal Size of Text Entry Boxes on PDAs

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ABSTRACT

This paper presents seven experiments to determine the optimal size of a box for the input of handwriting characters on PDAs. The experiments involve consideration of boxes for different kinds of characters, different sizes and shapes (square and rectangular), the learning effect, and the age differences of users. The results are assessed in terms of high performance factors (e.g., high character recognition rates, minimal stroke protrusions outside the character box) and subjective ratings (e.g., ease of writing and minimum degree of fatigue). The results show that the optimal size of character boxes for the input of alphanumeric characters is 1.20 x 1.44 cm (rectangular), and for Kanji mixed with Kana characters and Hiragana & Katakana characters the optimal size is 1.44 x 1.44 cm (square). We believe that knowledge of the optimal size of a character input box will be useful for the design of the user interfaces of PDAs.

Keywords

PDAs, handwriting character boxes, non-alphanumeric character input

INTRODUCTION

PDAs (personal digital assistants) have brought great efficiency to our everyday life because of their portability and powerful functionality. One important branch of PDA studies is the focus on the user interface for character input [3]. There are two common methods for character input on PDAs: the stylus-based text (i.e. artificial alphabet) entry method: e.g., [6,7,8,10], and the handwriting character text (i.e. natural alphabet) entry method: e.g., [2]. The input of alphanumeric languages is best served by the former method. But numerous difficulties arise for users whose languages are not based on the Roman alphabet, e.g., Chinese, Japanese and many other non-alphabetic languages. For most Asian people, handwriting is a better choice because, in countries like China and Japan, people use non-alphanumeric characters.

For handwriting, Palm OS PDAs provide two hardware boxes. Most other devices/applications display character boxes (i.e., on the screen), while some provide unframed input interfaces. Writing characters into unframed areas seems natural for users, however current character recognition technology prefers input into a defined area for accurate character recognition and error correction [8]. Moreover, in unframed input interfaces, buttons for error correction are needed in the limited screen space and, if errors occur, users have to select these buttons to affect corrections. Furthermore, users cannot write as freely in the limited screen space of a PDA as they can on the surface of normal writing paper and so they tend to make more mistakes. For these reasons, writing in boxes is more efficient than writing in an unframed area. Furthermore, there are many situations where character recognition is not immediately required but where input boxes/frames are still required for character input, e.g., entry boxes for names, addresses and dates. The handwritten characters may be recognized later, when required. Thus, comprehensive and intensive research on handwriting character boxes is necessary.

Handwriting character input box sizes on PDAs differ according to the software application for which they are to be used. Nowadays, there is no agreed standard for PDA user interface design. For example, at present, there are two main kinds of PDA operating systems on the market: Palm OS and Pocket PC OS. In the Palm PDA, there are two hardware boxes for handwriting, regardless of the software applications the subject is using. In the Pocket PC OS, two boxes appear on the screen for handwriting input while the different kinds of functions or applications are in use. However there are some exceptions, e.g., some software applications for handwritten character input on PDA OSs currently on the market have from 1 to 8 character input boxes, and the ATOK Pocket[1] for Palm OS uses a software

[1] ATOK means Advanced Technology of Kana & Kanji Transfer, a Japanese input system which is the same as Microsoft IME (input method editor). ATOK Pocket is used on mobile phones or PDAs.

box rather than the hardware boxes. Nevertheless, the design method by which PDA manufacturers determine the sizes of these boxes has never been reported.

PDA screen allocation must compromise between space for the writing boxes and space for information display. Therefore, once we decide the optimal size of the pen-input box, we can decide the number of boxes to allocate while leaving enough space for information display. Furthermore, when a handwriting character database is established we will first need to determine the standard size of writing character boxes for handwriting input.

However, current studies on PDA user interfaces are mostly related to pointing/selection issues, text entry methods and handwriting character recognition itself. The study of handwriting character box sizes has not been developed or reported in the literature until now, even though input boxes perform an essential function and a lot of problems are associated with their size and shape. The work of Ren and colleagues [1,4] is a notable exception. They have studied some of the issues on a Wacom LCD Tablet (B5 size) but not on a PDA. Moreover, some of the basic issues and factors relating to the size and shape of handwriting character boxes, such as the age of users, the learning effects and posture, were not considered. Except for the work described above, no other work has been done on this topic. Wobbrock et al. [9] paid attention to a novel input method which specifically uses a physical box to bound input rather than paying attention to the size of box itself.

Therefore, we developed this intensive study on the effects of different kinds of boxes on PDA user performance. Our purpose is to find the optimal size for an input box for handwriting on a PDA screen. Here we assume that an optimal size exists and that it can be determined by the consideration of certain factors. Thus, at first, we determined the optimal size of a box as having the following characteristics: high performance (e.g., a high character recognition rate, a minimum number of strokes protruding out from the character box) and high subjective ratings (e.g., including ease of writing and a minimum degree of fatigue).

EXPERIMENT 1: BOX SIZE

The goal of this experiment was to determine the optimal size for handwriting character entry boxes. Chinese characters (called "Kanji" in Japanese) mixed with Japanese Kana (phonetic) symbols, Hiragana and Katakana, and alphanumeric characters were used in the experiments.

Participants

Eleven Japanese subjects and one Chinese subject (who also had a high level of proficiency in writing Japanese) were tested. The average age was 22.8 (6 male and 6 female; all right-handed). Two of them had had about 1 -- 1.5 years of experience in PDA use. The others had no experience.

Apparatus

The hardware used in the experiment was the PDA iPAQ Pocket PC running Windows CE 3.0. It weighed about 190g, and was 84 mm (W) x 16 mm (D) x 134 mm (H). The spatial resolution of the screen was 0.24 mm/pixel. The software for the experiment was developed using Microsoft embedded Visual C++.

Figure 1. Experimental interface (in the case of Kanji & Kana)

Design

In this experiment, we set two boxes on the PDA screen. This is a common configuration. In the experiment, characters included alphanumeric, Hiragana & Katakana, and Kanji & Kana. We designed five kinds of square boxes for testing each of the three kinds of character sets. The sizes of the square boxes tested were as follows:

- 10 x 10 pixels (0.24 x 0.24 cm)
- 20 x 20 pixels (0.48 x 0.48 cm)
- 40 x 40 pixels (0.96 x 0.96 cm)
- 60 x 60 pixels (1.44 x 1.44 cm)
- 80 x 80 pixels (1.92 x 1.92 cm)

The 1.92 x 1.92 cm box is the standard size for the Pocket PC. The other square box sizes were selected by decreasing from this size in 10 or 20 pixel increments for each side. On the limited width of the PDA screen, there is not enough space for boxes bigger than the 1.92 x 1.92 cm if we want to display two boxes side by side and if we want to display the "Space" and "Delete" icons in the lower third of the screen (see Figure 1).

We also used 0.61 x 1.18 cm (25 x 49 pixels) for alphanumeric, 0.82 x 1.15 cm (34 x 48 pixels) for Hiragana & Katakana, and 0.94 x 1.38 cm (39 x 57 pixels) for Kanji & Kana, as baselines for each of the three kinds of character sets. These sizes were established by Ren and Moriya [4]. Thus, for each of the three kinds of character sets, we tested six kinds of boxes.

Task

First, the outline of the experiment was explained to the subjects. In order to familiarize them with the experimental environment, we set a practice session for each kind of character set and the related box. The subject was asked to input the upper and lower case alphabet characters (A--Z, a--z) once each, and the numbers (0--9) twice, then to input some sentences in Hiragana, Katakana and Kanji.

Figure 1 shows a screenshot of the experiments. The target character, which the subject was to input by pen, was displayed and highlighted in pink in the middle section together with other candidate characters. The two character input boxes were displayed on the lower section of the screen. The characters actually input into the boxes by the subject were displayed in the upper section of the screen.

For each of the three kinds of character sets and each of the six kinds of boxes in relation to the each character type, the procedure to input a character was as follows: the subject identified the target character and input it into one of the boxes with the pen. The character that had been written was then displayed without recognition in the upper section of the screen. When the subject finished writing the complete character, the next target character was highlighted in pink. A space was inserted between two characters whenever the subject used the pen to touch the “Space" icon in the lower right of the screen. Touching the “Delete" icon had the effect of tapping the backspace key on a keyboard. The subject could use this icon to remove any character that they wanted to rewrite or correct, e.g., when the character which was written by the subject was an incorrect character.

The character recognition function was not carried out during the test. The character recognition rate was derived from the data after the experiment. In this way the subject would not feel stress caused by having to rewrite a character when the wrong character recognition result was displayed. Since the purpose was to evaluate the optimal box size, we wanted to eliminate any excessive stress.

All subjects were in a sitting posture and all held the PDA in the hand. After the input of all characters was completed, the subject was asked to rate the following: ease of writing, degree of relaxation, box size preference, and overall evaluation on a scale from 1 (worst) to 7 (best) [2].

Each subject tested the six box sizes in a different order (partial counterbalancing). A ten minute break was inserted between tests of each box size.

After one round of one kind of character set, the subject would resume the experiment using another kind of character set in a different order. Subjects did not know that the test related to box size and shape, and they were not told that the box sizes were different.

The total number of characters tested in the experiment were 5184 for alphanumeric characters ((26(upper case English characters) + 26(lower case English characters) + 20(Numbers twice)) x 6(boxes) x 12(subjects)); 5544 for Hiragana & Kakakana characters (77(Hiragana & Katakana) x 6(boxes) x 12(subjects)), and 5400 for Kanji & Kana (75(Kanji & Kana) x 6(boxes) x 12(subjects)).

At the end of the experiment, the number of protruding strokes, the number of error corrections, and the time taken to input each character into the box were recorded. The number of error corrections was measured by the number of times the “Delete" icon was touched. The writing time for each character was measured from the moment the subject started to write the character to the instant the character was displayed on the upper section of the screen.

Evaluation indices included character recognition rate, the number of protruding strokes, the number of error corrections, average writing time for one character, and questionnaires.

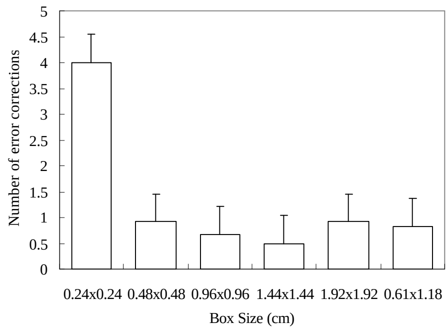

Figure 2. The number of error corrections in each of six box sizes for alphanumeric characters in Experiment 1 (with standard error bars).

Results

Alphanumeric

No significant difference between the six boxes was found in writing time. Significant differences between the six boxes were found in error corrections, $F(5,66) = 3.69$, $p < 0.05$, and in the number of protruding strokes, $F(5,66) = 32.96$, $p < .001$. The 1.44 x 1.44 cm box had the least number of error corrections (mean = 0.50, see Figure 2). The number of protruding strokes ranged from the 0.61 x 1.18 cm box, 1.44 x 1.44 cm box, to 0.96 x 0.96 cm box. The 0.61 x 1.18 cm box had the lowest number of protruding strokes (mean = 0.25), however, there was no significant difference among these three boxes. A significant difference between the six boxes was also found in character recognition rate, $F(5,66) = 6.56$, $p < .001$. Although the rate of recognition for the 0.96 x 0.96 cm box (mean = 72.80%) was higher than that for the 1.44 x 1.44 cm box (mean = 72.69%), the post hoc Tukey HSD test showed that there was no significant difference between the two boxes.

We analyzed the average value of the answers given by the subjects to 4 questions. The 1.44 x 1.44 cm box received high ratings (mean = 6.19) from the questionnaire, $F(5,18) = 109.04$, $p < .0001$. The post hoc Tukey HSD test showed

[2] We also asked the subjects to rate “readability", however, the definition was difficult for them grasp, thus we omitted the data.

no significant differences between 1.44 x 1.44 cm and each of 0.96 x 0.96 cm, and 1.92 x 1.92 cm boxes, between 0.96 x 0.96 cm and each of 1.92 x 1.92 cm, and 0.61 x 1.18 cm boxes, between 1.92 x 1.92 cm and 0.61 x 1.18 cm boxes, however, a significant difference was found between 1.44 x 1.44 and 0.61 x 1.18, $p < .05$.

According to the above results, we can conclude that the 1.44 x 1.44 cm box is the optimal box for alphanumeric character input.

Hiragana & Katakana

No significant difference between the six boxes was found in writing time or the number of error corrections. Although 1.92 x 1.92 cm box had the lowest number of protruding strokes (mean = 0.58) among the six boxes, $F(5,66) = 23.87$, $p < .001$, there was no significant difference among the 1.92 x 1.92 cm, 1.44 x 1.44 cm, 0.82 x 1.15 cm and 0.96 x 0.96 cm boxes.

A significant difference between the six boxes was also found in character recognition rate, $F(5,66) = 12.72$, $p < .001$. The rates of recognition ranged from the 1.44 x 1.44 cm box (mean = 82.90%), 0.82 x 1.15 cm box (mean = 82.79%), 1.92 x 1.92 cm box (mean = 82.25%), to 0.96 x 0.96 cm box (mean = 81.28%). However, there was no significant difference among the four boxes.

Moreover, the 1.44 x 1.44 cm box received the highest ratings (mean = 5.94) from the questionnaire, $F(5,18) = 188.87$, $p < .0001$. The post hoc Tukey HSD test showed no significant differences between 1.44 x 1.44 cm box and each of 0.96 x 0.96 cm box, and 0.82 x 1.15 cm box, between 0.96 x 0.96 cm box and each of 1.92 x 1.92 cm box, and 0.82 x 1.15 cm box, between 1.92 x 1.92 cm box and 0.82 x 1.15 cm box, however, a significant difference was found between the 1.44 x 1.44 cm box and 1.92 x 1.92 cm box, $p < .05$.

According to the above results, we can conclude that the 1.44 x 1.44 cm box is the optimal size for Hiragana & Katakana character input.

Kana & Kanji

No significant difference between the six kinds of boxes was found in writing time.

There was a significant difference between the six boxes, $F(5,66) = 3.20$, $p < .05$. The 1.44 x 1.44 and 1.92 x 1.92 cm boxes had fewer error corrections (mean = 0.42, 0.33 respectively) than the other boxes. However there was no significant difference between these two box sizes.

A significant difference between the six boxes was found in the number of protruding strokes, $F(5,66) = 25.44$, $p < .001$. The 1.44 x 1.44 cm box and the 1.92 x 1.92 cm box had fewer protruding strokes (each with a of mean = 0.58). However, there was no significant difference between these two box sizes.

Figure 3 shows the experimental results for character recognition rates. A significant difference between the six boxes was found in character recognition rate, $F(5,66) = 18.70$, $p < .001$. The rates of recognition were: 1.92 x 1.92 cm box (mean = 92.56%), 0.96 x 0.96 cm box (mean = 92.11%), 1.44 x 1.44 cm box (mean = 91.67%). However, there was no significant difference among these three box sizes.

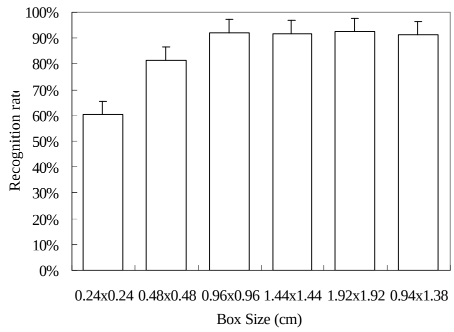

Figure 3. The recognition rates in each of six box sizes for Kanji & Kana in Experiment 1

Moreover, the 1.44 x 1.44 cm box received the highest ratings (mean = 5.88) from the questionnaire, $F(5,18) = 171.35$, $p < .0001$. The post hoc Tukey HSD test showed no significant differences between each pair of 1.44 x 1.44, 0.96 x 0.96, 1.92 x 1.92 and 0.94 x 1.38. Significant differences were found between each of 0.24 x 0.24 and 0.48 x 0.48, and each of 1.44 x 1.44, 0.96 x 0.96, 1.92 x 1.92 and 0.94 x 1.38, $p < .0001$.

Overall, 1.44 x 1.44 and 1.92 x 1.92 cm boxes received higher performance and subjective ratings than the other boxes. Since the PDA screen has limited space, thus we determined that the 1.44 x 1.44 cm box is the optimal box for Kana & Kanji character input.

Discussion

From the above results, we can conclude that the optimal box size for all three kinds of character input is 1.44 x 1.44 cm. The results showed that the different boxes mainly affect the number of protruding strokes and the recognition rate when writing into a PDA. Furthermore, the results also indicated that bigger was not necessarily better. This means that there is an optimal box size, and people will feel comfortable and work more efficiently with this kind of box.

EXPERIMENT 2: BOX SHAPE

The results in Experiment 1 were derived from the square box design. In the next section, we ask whether the shape of the input box has any effect when writing characters on a PDA screen.

Participants

Twelve Japanese subjects, average age 21.4 years old, participated in this experiment (10 male and 2 female; all right-handed). One of them had about 1 year experience in

PDA use. The others had no experience. Some of them had participated in Experiment 1.

Design

The apparatus, software and character kinds used in the experiment were the same as in Experiment 1. We designed two character box shapes: rectangular and square. The sizes for each kind of character set are shown below.

(1) Alphanumeric character

- Square: 0.96 x 0.96 (40 x 40 pixels), 1.20 x 1.20 (50 x 50 pixels), 1.44 x 1.44 (60 x 60 pixels) cm
- Rectangle (width x height): 0.61 x 1.18 (25 x 49 pixels), 0.85 x 1.42 (35 x 59 pixels), 1.09 x 1.66 (45 x 69 pixels) cm

(2) Hiragana & Katakana

- Square: 1.20 x 1.20, 1.44 x 1.44, 1.68 x 1.68 (70 x 70 pixels) cm
- Rectangle: 0.82 x 1.15 (34 x 48 pixels), 1.06 x 1.38 (44 x 58 pixels), 1.30 x 1.62 (54 x 68 pixels) cm

(3) Kana & Kanji

- Square: 1.20 x 1.20, 1.44 x 1.44, 1.68 x 1.68 cm
- Rectangle: 0.96 x 1.38 (39 x 57 pixels), 1.18 x 1.62 (49 x 68 pixels), 1.42 x 1.86 (59 x 78 pixels) cm

The rectangular input boxes, the 0.61 x 1.18 cm (for alphanumeric), 0.82 x 1.15 cm (for Hiragana & Katakana), and 0.96 x 1.38 cm (for Kana & Kanji) boxes were designed according to the quasi-optimal sizes of the alphanumeric, Kana & Kanji characters input boxes, previously determined by Ren and Moriya [4]. We used their findings as the baseline for comparison. The other rectangular boxes were enlarged in increments of 10 pixels in width and height based on the three boxes. The square input box 1.44 x 1.44 cm was the optimal size determined by Experiment 1. The other square boxes were enlarged or reduced in increments of 10 pixels in the width and height based on the three boxes.

Task

The experimental procedure and evaluation indices were the same as in Experiment 1. Each subject used six kinds of boxes in relation to each character type and three kinds of characters sets were tested in different orders. The subjects input a total of 4464 alphanumeric, 2952 Hiragana & Katakana, and 2232 Kanji & Kana characters.

Results

No significant differences appeared between the six boxes in each of the evaluation indices for each of three kinds of characters.

Thus, we looked at the results of the questionnaires. Regarding Hiragana & Katakana. Here we found that there was a significant difference between the six boxes, $F(5,18) = 9.66$, $p < .001$. The 1.30 x 1.62 cm box received the highest ratings (mean = 5.44), and the next was the 1.44 x 1.44 cm box (mean = 5.10). However, the post hoc analysis showed no significant difference between the two boxes. For Kanji & Kana, there was a significant difference between the six boxes, $F(5,18) = 27.28$, $p < .001$. The 1.42 x 1.86 cm box received the highest ratings from the questionnaire (mean = 5.27), and the next was 1.68 x 1.68 cm (mean = 4.92), 1.44 x 1.44 cm (mean = 4.85). However, the post hoc analysis showed no significant difference between the three boxes. Nine of the twelve participants commented that they felt that it was easier to write Hiragana, Katakana and Kanji in quite big square boxes. Taking the results of Experiment 1 together with the subjective comments, we determined that the 1.44 x 1.44 cm box is a good choice for the input of Hiragana & Katakana, and for Kanji & Kana.

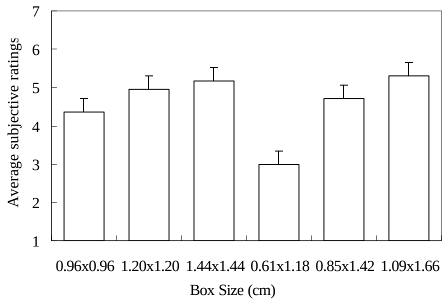

Figure 4. Subjective overall evaluation for alphanumeric characters in Experiment 2 (1 = lowest preference, 7 = highest preference).

Figure 4 shows the subjective ratings for alphanumeric input. There was a significant difference between the six boxes, $F(5,18) = 37.29$, $p < .0001$. The 1.09 x 1.66 cm box received the highest ratings (mean = 5.31), however there was no significant difference between each pair of 1.20 x 1.20, 1.44 x 1.44, 0.85 x 1.42, and 1.09 x 1.66. Ten of the twelve participants pointed out that they felt it was easier to write alphanumeric characters in these rectangular boxes. Thus, we could see that the rectangular boxes ranging from 0.85 x 1.20 to 1.44 x 1.66 cm were preferred for alphanumeric character writing.

Discussion

The results showed no difference between the six boxes for each of the three kinds of characters. This can be explained by the fact that the sizes of these boxes were not so different because they were enlarged by only 0.24 cm in width and height based on the optimal size determined in Experiment 1 for the square boxes or the quasi-optimal size previously established for the rectangular boxes [4].

Through the experiment on box shape, we noticed that most subjects preferred to use square boxes to input Hiragana, Katakana, and Kanji. This is because most Hiragana, Katakana, and Kanji are square in shape and they require many more strokes. It is more comfortable to input them into square boxes.

On the other hand, most subjects prefer to use rectangular boxes when they input alphanumeric characters. This is because alphanumeric characters are mostly rectangular in shape and it is easier and more comfortable to input them into rectangular rather than square boxes.

However, the optimal size for alphanumeric character writing included a large range (from 0.85 x 1.20 to 1.44 x 1.66 cm) so that we could say only that there was an optimal range rather than one optimal size for rectangular boxes. The reason may lie in the fact that the rectangular boxes used in Experiment 2 all had different aspect ratios. Whether the result depends on the aspect ratio is still not clear.

EXPERIMENT 3: RECTANGULAR BOX SIZE

The goal of this experiment was to determine the optimal rectangular box size using the same ratios.

Participants

Twelve Japanese subjects were tested. The average age was 21.9 (8 male and 4 female; all right-handed). Four of them had about 1 -- 2 years previous experience in PDA use. The others had no experience. Some of them had participated in Experiment 1 and/or Experiment 2.

Design

The apparatus and software used in the experiment were the same as in Experiment 1. We also set two input boxes on the PDA screen, as in Experiment 1. Characters included alphanumeric and Kana & Kanji[3]. The sizes for each kind of character are shown below.

(1) Alphanumeric characters with the same ratio:

- 25 x 49 pixels (0.61 x 1.18 cm)
- 31 x 60 pixels (0.74 x 1.44 cm)
- 36 x 71 pixels (0.86 x 1.70 cm)

(2) Kana & Kanji with the same ratio:

- 39 x 57 pixels (0.96 x 1.38 cm)
- 47 x 68 pixels (1.13 x 1.63 cm)
- 54 x 79 pixels (1.30 x 1.90 cm)

The rectangular input boxes, the 0.61 x 1.18 cm (for alphanumeric), and 0.96 x 1.38 cm (for Kana & Kanji) boxes were designed according to the quasi-optimal sizes of the alphanumeric, Kana & Kanji characters input boxes previously determined by Ren and Moriya [4]. We used the ratio (H/W) as the baseline. The other rectangular boxes were enlarged in 11 pixel increments in height based on the two boxes. The widths were based on the two baseline ratios.

Task

The experimental procedure and evaluation indices were the same as in Experiment 2. The difference is that we asked the subject to input the target character into the boxes "as quickly and clearly as possible". Thus, besides the number of protruding strokes, the number of error corrections, and the time taken to input each character into the box, the time taken to move the pen between the two boxes was also recorded. The pen movement time was measured as the moment from when the subject finished writing one character to the moment when the subject started to write the next character.

The total number of characters tested in the experiment were 2232 for alphanumeric characters ((26(upper case English characters) + 26(lower case English characters) + 10(Numbers once)) x 3(boxes) x 12(subjects)), and 2484 for Kana & Kanji (69(Kana & Kanji) x 3(boxes) x 12(subjects)).

Results

Alphanumeric

No significant differences were observed between the three boxes in each of the evaluation indices. Regarding the subjective ratings, there was a significant difference between the three boxes, $F(2,9) = 52.54$, $p < .001$. The 0.86 x 1.70 cm box received the highest ratings (mean = 5.0), and the next was 0.74 x 1.44 cm (mean = 4.96). However, the post hoc analysis showed no significant difference between the two boxes. Moreover, the majority of the participants preferred the 0.74 x 1.44 cm box for alphanumeric input. According to the above results, we can conclude that the 0.74 x 1.44 cm box was the optimal box for alphanumeric character input.

Kana & Kanji

No significant differences were observed between the three boxes in each of the evaluation indices. Regarding the subjective ratings, there was a significant difference between the three boxes, $F(2,9) = 5.19$, $p < .05$. The 1.13 x 1.63 cm box received the highest ratings (mean = 4.81), and the next was 1.30 x 1.90 cm (mean = 4.60). However, the post hoc analysis showed no significant difference between the two boxes. Moreover, the majority of the participants (five--eighths) preferred the 1.13 x 1.63 cm box for Kana & Kanji. They said that it was easier to write Kanji & Kana characters in this box. Therefore, we concluded that the 1.13 x 1.63 cm box was the optimal box size for Kana & Kanji character input.

[3] We omitted Hiragana & Katakana in this experiment because the result for Hiragana & Katakana was the same as Kanji & Kana; and it is included in Kanji & Kana; and we also wanted to reduce the Experimental load.

Discussions

The results showed that there was no difference between the three boxes for each of two kinds of characters. The reason may lie in the fact that the choice of the experimental box sizes was based on the quasi-optimal size established by Ren and Moriya [4] and the sizes of the boxes tested were not so different. Concerning the questionnaire and subjects' comments, the rectangular optimal size for each of two kinds of characters were determined to be 0.74 x 1.44 cm for alphanumeric and 1.13 x 1.63 cm for Kana & Kanji.

EXPERIMENT 4: RECTANGULAR VS. SQUARE BOXES

The results in Experiment 3 were based on the fact that only rectangular boxes were tested. Thus, we compared the results of Experiment 3 with the optimal square box (i.e., 1.44 x 1.44 cm box) which was determined by Experiments 1 and 2.

Participants

Twelve Japanese subjects were tested. The average age was 21.3 (8 male and 4 female; all right-handed). One of them had about a year previous experience in PDA use. The others had no experience. Some of them had participated in Experiments 1, 2 and/or 3.

Design

The apparatus, software, character kinds, experimental procedure and evaluation indices used in the experiment were the same as in Experiment 3.

The sizes for each kind of character are shown below.

(1) Alphanumeric characters

- Square: 60 x 60 pixels (1.44 x 1.44 cm)
- Rectangle: 31 x 60 pixels (0.74 x 1.44 cm)

(2) Kana & Kanji

- Square: 60 x 60 pixels
- Rectangle: 47 x 68 pixels (1.13 x 1.63 cm)

The rectangular input boxes, 0.74 x 1.44 cm for alphanumeric and 1.13 x 1.63 cm for Kana & Kanji were the optimal sizes determined by Experiment 3. The square input box, 1.44 x 1.44 cm was chosen according to the results of Experiments 1 and 2. The subjects input a total of 1488 alphanumeric, and 1656 Kana & Kanji characters.

Results

Alphanumeric

No significant differences were found between the two boxes in each of the evaluation indices. Regarding the subjective ratings, the 1.44 x 1.44 cm box received high ratings (mean = 5.31), $F(1,6) = 12.63$, $p < .05$. However, half of the participants commented that they preferred the rectangular box for writing alphanumeric characters.

Kana & Kanji

The experimental data showed no significant differences between the two boxes in each of the evaluation indices, and the questionnaire. However, the majority of the participants (three quarters) commented that they preferred to write Kana & Kanji in 1.44 x 1.44 cm square box.

Discussions

The subjects preferred the 1.44 x 1.44 cm box. The reason may be that most Kanji are square in shape. With reference to alphanumeric input, there was some contradiction between the subjects' comments and the results of questionnaires, i.e., half of the participants preferred the rectangular box for writing alphanumeric characters, however, the 1.44 x 1.44 cm square box received higher ratings than the rectangular box. The contradiction between the data and some of the subjective responses may well relate to the artistic proportions to which some people instinctively adhere through conditioning rather than to efficiency criteria. Moreover, some participants commented that they wanted to try some box sizes between the box sizes tested. Therefore, we performed a further experiment described in Experiment 5.

EXPERIMENT 5: EXPERIMENT 4 - ADDITIONAL TEST

Participants

Twelve Japanese subjects were tested for the experiment. The average age was 21.5 (8 male and 4 female; all right-handed). One of them had about a year previous experience in PDA use. The others had no experience. Some of them had participated in Experiments 1, 2, 3 and/or 4.

Design

The apparatus, software, experimental procedure and evaluation indices used in the experiment were the same as in Experiment 3. Four character box sizes were designed for alphanumeric input. The sizes are shown as below.

- 31 x 60 pixels (0.74 x 1.44 cm)
- 40 x 60 pixels (0.96 x 1.44 cm)
- 50 x 60 pixels (1.20 x 1.44 cm)
- 60 x 60 pixels (1.44 x 1.44 cm)

The 0.74 x 1.44 cm and 1.44 x 1.44 cm boxes were chosen according to Experiment 4. The subjects input a total of 3456 alphanumeric characters.

Results and Discussions

No significant differences were found between the four boxes in each of the evaluation indices. Thus, we looked at the results of the questionnaires (see Figure 5). The 1.20 x 1.44 cm box received the highest ratings (mean = 5.69), $F(3,12) = 10.28$, $p < .01$. Moreover, over half of the participants commented that they felt that it was easier to write alphanumeric characters in the 1.20 x 1.44 cm box.

The results showed no significant difference between the four boxes. However, the subjective comments showed that the box shape which was the easiest to write alphanumeric characters in was the rectangular box. The reason can be considered to be that most alphanumeric characters are rectangular in shape. Thus, we concluded that the 1.20 x 1.44 cm rectangular box is the optimal box for alphanumeric character input on PDAs.

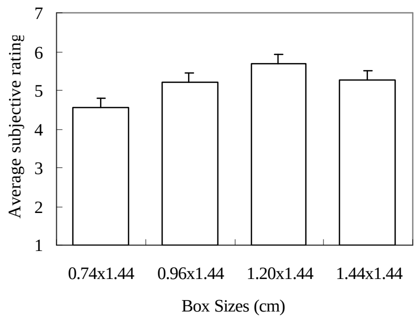

Figure 5. Subjective results for alphanumeric characters (1 = lowest preference, 7 = highest preference).

EXPERIMENT 6: LEARNING EFFECTS AND USER POSTURES

The results of Experiments 1--5 revealed the optimal sizes of boxes. However, these experiments did not consider the learning effects and user postures while inputting handwriting characters into the boxes. Whether the result depends on the learning effects and user postures was still not clear. Thus, we sought to determine the optimal size box with consideration being given to user postures and the learning effects when handwriting on PDAs.

In Experiments 1--5, we gave no special consideration to recruiting subjects with or without PDA experience. However, in Experiment 6, we chose twelve Japanese subjects (average age 21.3, 9 male and 3 female; all right-handed) who had never used a PDA and had not been involved in Experiments 1--5.

Design

The apparatus and software used in the experiment were the same as in Experiment 3. This experiment used Kana & Kanji. The sizes tested were as follows:

- 40 x 40 pixels (0.96 x 0.96 cm)
- 50 x 50 pixels (1.20 x 1.20 cm)
- 60 x 60 pixels (1.44 x 1.44 cm)

The 1.44 x 1.44 cm input box for Kana & Kanji was the optimal size determined by Experiments 1--4. The other boxes were narrowed by increments of 10 pixels based on the baseline box.

The experimental procedure and evaluation indices were the same as in Experiment 3. The difference is that the twelve subjects were divided into two groups: six subjects in sitting postures and the other subjects in standing postures.

The total number of characters tested in the experiment were 21,600 (100(Kana & Kanji) x 3(boxes) x 12(subjects) x 6(blocks)).

Results and Discussion

No significant difference between the three boxes was found in each of the six blocks in terms of recognition rate, writing times, pen movement times and the number of error corrections in each of the two postures.

Regarding the number of protruding strokes: for the sitting posture, the post hoc analysis showed that the 1.44 x 1.44 box had fewer protruding stokes than the 0.96 x 0.96 box (p < .05); no significant differences were found between the 1.20 x 1.20 box and each of the other two boxes in the 3rd and the 6th blocks, however no significant differences were found between each pair of three boxes in each of the other blocks. For the standing posture, no significant differences were found between each pair of the three boxes in each of the six blocks.

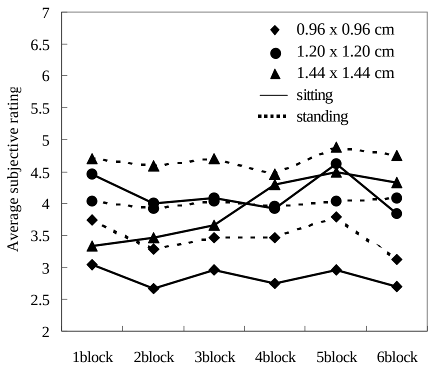

Figure 6. Average subjective ratings

Figure 6 shows the subjective ratings according to each block. These ratings were based on the average value of the answers given by the subjects to 4 questions. The post hoc analysis for sitting postures showed that the 1.20 x 1.20 cm box received higher ratings than the 0.96 x 0.96 cm and the 1.44 x 1.44 cm boxes (p ranged from 0.001 to 0.05) and no significant difference was found between the 1.20 x 1.20 cm and 1.44 x 1.44 cm boxes in the first three blocks. The analysis also showed no significant difference was found between the 1.20 x 1.20 cm and 1.44 x 1.44 cm boxes but they were all better than the 0.96 x 0.96 box (p ranged from 0.0001 to 0.05) in the last three blocks. The post hoc analysis for standing postures showed that 1.44 x 1.44 cm box received higher ratings than the 0.96 x 0.96 cm box (p ranged from 0.01 to 0.05), the 1.44 x 1.44 cm box was better than the 1.20 x 1.20 cm box (p < .05) and no significant differences were found between the 1.44 x 1.44 cm and 1.20 x 1.20 cm boxes, from the 2nd to the 6th blocks.

The subjective ratings for the sitting posture showed that subjects preferred the 1.20 x 1.20 cm box in the first block, however the subjective evaluations for the 1.44 x 1.44 cm and 1.20 x 1.20 cm boxes were the same from the 2nd to 6th blocks. The reason may lie in the fact that all subjects were novices so that they wrote the characters very carefully and filled the box when writing the characters in the first block.

Taking the results together we can conclude that the optimal size of a character box for the input of Kanji & Kana is still 1.44 x 1.44 cm, for both sitting and standing postures.

EXPERIMENT 7: OLDER USERS

We have shown the optimal sizes of boxes through Experiments 1--6. However, these experimental participants were younger users. Until recently, few research studies have attempted to examine how older adults write characters on PDAs. Thus, twelve older adult Japanese subjects (average age 63.3, all right-handed) who had never used PDAs and had not been involved in Experiments 1--6 were recruited for Experiment 7. The aim was to determine the optimal size of pen-input box for older users; i.e., to learn whether the aging process affects the optimal size of pen-input boxes, and whether there were differences in performance between younger and older adults groups.

Design

The apparatus and software used in the experiment were the same as in Experiment 3. The experiment used Kana & Kanji because the subjects could not understand English very well. The sizes tested were as follows:

- 40 x 40 pixels (0.96 x 0.96 cm)
- 60 x 60 pixels (1.44 x 1.44 cm)
- 80 x 80 pixels (1.92 x 1.92 cm)
- 100 x 100 pixels (2.40 x 2.40 cm)[4]

The 1.44 x 1.44 cm input box for Kana & Kanji was the optimal size determined by Experiments 1--4. The other boxes were changed by increments of 20 pixels based on the box.

The experimental procedure and evaluation indices were the same as in Experiment 3. The difference is that all subjects tested three blocks in the same procedure.

The total numbers tested by the experiment were 2736 for Kana & Kanji (19 Kana & Kanji x 4 boxes x 12 subjects x 3 blocks).

Results and Discussion

No significant differences were found between the four boxes in each of the three blocks in terms of recognition rate, writing times and pen movement times between the two boxes, and the number of error corrections.

Significant differences between the four boxes were found in the number of protruding strokes in each of the three blocks, $F(3,44) = 11.7$, $p < .001$ for the first block, $F(3,44) = 7.05$, $p < .001$ for the second block, and $F(3,44) = 8.87$, $p < .001$ for the third block. However, there was no significant difference among the 2.40 x 2.40 cm, 1.92 x 1.92 cm, and 1.44 x 1.44 cm boxes.

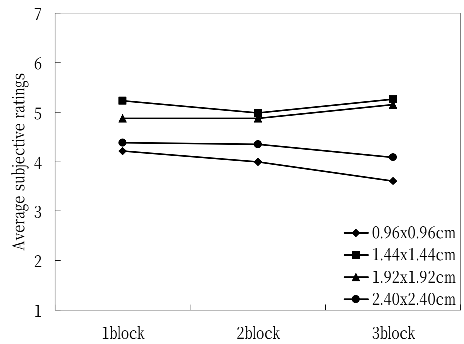

Figure 7. Average subjective ratings

Figure 7 shows the subjective ratings according to each of the three blocks. A significant difference between the four boxes was found in the subjective ratings in the third block, $F(3,44) = 4.70$, $p < .01$. The 1.44 x 1.44 cm box received the highest ratings.

Based on the above results, we concluded that the optimal character box size was the 1.44 x 1.44 cm box. This result was same as for the younger groups. It was known that the normal effects of aging include some decline in cognitive, perceptual, and motor abilities [5]. However, our experimental results show that the optimal size of boxes was not influenced by age specificity. This was a particularly interesting finding for the older adults.

However, there was a significant difference in writing time between the older group's data and the younger groups' data which was obtained in Experiment 4, $F(1,22) = 6.52$, $p < .05$. The older users wrote characters more slowly than the younger users. Furthermore, there was a significant difference in pen-movement time between the two boxes, $F(1,22) = 11.42$, $p < .01$; the older users move the pen more slowly than the younger users. These differences between the two groups were affected by bodily factors. This agrees with Salthouse [5].

GENERAL DISCUSSIONS AND CONCLUSIONS

In a set of seven experiments we determined the optimal shape and size of a character input boxes for various character sets which allow users to input handwriting comfortably and efficiently. Based on the results of the

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[4] We deleted the "Space" icon because no space was input in the experiment and we placed the "Delete" icon under the two boxes in order to make the two input boxes bigger because we assumed the older adults would prefer bigger boxes.

three experiments, we determined the optimal sizes as follows:

- Alphanumeric: 1.20 x 1.44 cm (rectangular)
- Kanji & Kana: 1.44 x 1.44 cm (square)
- Hiragana & Katakana: 1.44 x 1.44 cm (square)

Regarding shape, the principle appears to be as follows: it is more comfortable to input characters into boxes which approximate in shape to the characters themselves. Thus, as for the results of the Kana & Kanji, the evaluation of the square box was better than that of rectangular boxes. Furthermore, Kanji input requires more space due to the far greater number of strokes appearing in most Kanji characters. When writing alphanumeric characters, subjects tend to try to use the whole area of the square thus creating a conflict between the natural proportions of the character Hence the rectangular shape is preferred for alphanumeric characters. Furthermore, the movement time between two square boxes is greater than the movement time between two rectangular boxes. These factors make users uncomfortable when using the square box for alphanumeric input.

Regarding the current sizes of text entry boxes, the standard size of text entry boxes for Pocket PCs is 1.92 x 1.92 cm; The Palm OS entry box is about 1.65 x 1.90 cm. However, the optimal box size we determined is 1.20 x 1.44 (alphanumeric) – 1.44 x 1.44 (Katakana & Hiragana, Kanji & Kana). The differences between the optimal size and Poctket PC standard size, and between the optimal size and Palm OS box size are around 0.72 x 0.48 – 0.48 x 0.48 cm, 0.45 x 0.46 – 0.21 x 0.46 cm respectively. The difference between the optimal size determined by this work and the current sizes is significant because it shows that if the optimal sizes that we have determined are applied to PDA devices, more display space can be assigned to the display of information without any loss of input efficiency, and possibly with some gains in input efficiency.

Our investigation has led to the following conclusions.

First, these results may be regarded as reflecting universal characteristics of the human use of character input boxes. We tested a large number of subjects including younger and older adult users, as well as users who had never used a PDA; we gave consideration to the learning effect as well as to the effects of sitting & standing postures. Furthermore, in our experiments, subjects input several thousands of commonly used characters including all English the letters and Arabic numerals and various Asian character sets. These adequately represented the normal range for handwriting on PDAs for a significant range of languages and character types.

Second, these results show that it is not necessarily true that users perform better with bigger boxes, i.e., sacrificing the information space displayed around the boxes may not necessarily bring more benefits during input tasks.

Third, this study carried out experiments on the input boxes on PDAs, but the implications may go beyond PDA usage to tablet PCs, and other similar pen input interfaces. Some applications on tablet PCs or small handheld devices also display character boxes. There are many kinds of boxes for character input such as entry boxes for names, addresses and dates, money forms, commodity items, brachymorphic domains for sentence input, boxes for writing formulas, and so on.

We believe that the results of this study will be useful in designing handwriting character entry boxes and the interfaces of PDA screens, and in improving the advanced writing methods on other human computer interaction input systems.

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