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The Optimal Size of Handwriting Character Input Boxes on PDAs

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This article presents an empirical study to determine the optimal size of a box for the input of handwriting characters on personal digital assistants (PDAs). The experiments involve the consideration of boxes for different kinds of characters, different box sizes and shapes (square and rectangular), different user postures, and the age differences of users. The results are assessed in terms of high performance (high character recognition rates, minimal stroke protrusions outside the character box, minimal number of error corrections, minimum writing time) 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 12 × 14 mm (rectangular), whereas for Kanji (Chinese characters) mixed with Kana characters and for Hiragana & Katakana characters the optimal size is 14 × 14 mm (square). We believe that knowledge of the optimal size of character input boxes will be useful for the design of user interfaces on PDAs.

1. INTRODUCTION

Personal digital assistants (PDAs) 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 (MacKenzie & Soukoreff, 2002). There are two common methods of character input on PDAs that do not have a real keyboard: the stylus-based text (i.e., artificial alphabet) entry method (e.g., Sears, Revis, Swatski, Crittenden, & Shneiderman, 1993; Soukoreff & MacKenzie, 1995; Tanaka & Ishigaki, 2001; Zhai & Kristensson, 2003) and the handwriting character text (i.e., natural alphabet) entry method (e.g., MacKenzie,

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Nonnecke, Riddersma, McQueen, & Meltz, 1994). 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. This is particularly important in script languages, such as Chinese, Japanese, and many other nonalphabetic languages. For most Asian people, in countries like China and Japan, handwriting is a better choice because the use of nonalphanumeric characters to input text via keypad is difficult.

Current studies about handwriting input mainly focus on tasks and functions that are performed after the characters have been entered into the PDA, such as character recognition (Wang, Li, Ao, Wang, & Dai, 2003; Wobbrock, Myers, & Chau, 2006; Wobbrock, Myers, & Kembel, 2003) and pattern recognition. Researchers have seldom paid attention to the character input box. For handwriting, Palm OS PDAs provide two hardware boxes. Most other devices/applications display character boxes (i.e., on the screen), whereas 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 (Tanaka & Ishigaki, 2001). 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 make 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, for example, input 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. These days, 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 individual is using. In the Pocket PC OS, two boxes appear on the screen for handwriting input while different kinds of functions or applications are in use. However, there are some exceptions. For example, some software applications for handwritten character input on PDA operating systems currently on the market have from one to eight character input boxes, and the ATOK Pocket[1]for Palm OS uses a software box rather than hardware boxes. No design method by which PDA manufacturers determine the sizes of these boxes has been reported.

PDA screen allocation must find a balance between space for the input 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

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

enough space for information display. Furthermore, when a handwriting character database is established, it is important to standardize the character input box and find out what the optimal box size is. We 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, handwriting character input 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 (e.g., Kato, Ren, Sakai, & Machi, 2003; Ren & Moriya, 1995) 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 and the effects of various postures, were not considered. Except for the work just described, no other work has been done on this topic.

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).

This article is structured as follows. We first give an overview of all the experiments with their rationales and the anticipated results. Experiment 1 examines the effect of square boxes on input performance and attempts to define the optimal size for a square box for alphanumeric, Hiragana & Katakana, and Kanji & Kana characters input. In Experiment 2, we ask whether the shape (square or rectangular with various aspect ratios) of the input box has any effect when writing characters on a PDA screen. Experiment 3 examines and determines the optimal rectangular box size using the same aspect ratio. Experiment 4 compares the results of Experiment 3 with the optimal square box which is determined by Experiments 1 and 2. A further experiment described in Experiment 5 is performed to test additional rectangular boxes. The results of Experiments 1 to 5 have almost revealed the optimal sizes of boxes and are almost conclusive but for the need to consider some important subjective factors: user posture and age effects. Experiment 6 investigates the effects user postures and user age groups have on handwritten character input into the boxes. Finally, the results are discussed and conclusions are drawn.

2. EXPERIMENTAL RATIONALE AND HYPOTHESES

Experiment 1 tested six sizes of square boxes (with sizes ranging from the smallest, 2×2 mm, to the biggest, 19×19 mm) to examine their input performance for alphanumeric, Hiragana & Katakana, and Kanji & Kana characters, respectively. For the smaller boxes, more protruding strokes and a lower character recognition rate may be expected. For the bigger boxes, the user may feel tired and take more time to write characters in it. We therefore hypothesized that the optimal box size in this experiment may be within the middle range of the six box sizes.

Experiment 1 produced results for square boxes only and for no other shapes. Therefore, Experiment 2 tested both square and rectangular (with different aspect ratios) boxes to evaluate their input performance for alphanumeric, Hiragana & Katakana, and Kanji & Kana characters, respectively. We imagined that rectangular boxes would be more suitable for alphanumeric characters and that square boxes would be more suitable for Hiragana & Katakana and for Kanji & Kana characters. Most alphanumeric characters are rectangular in shape, and we imagined that it would be easier and more comfortable to input them into rectangular rather than square boxes, whereas most Hiragana, Katakana, and Kanji characters are square in shape, and we imagined that it might be more comfortable to input them into square boxes.

The results of Experiment 2 posed the question of whether the experimental results depend on the aspect ratio. Therefore, Experiment 3 used rectangular boxes with the same aspect ratio to test the input performance for alphanumeric (three box sizes ranging from 6×12 mm to 9×17 mm) and Kanji & Kana (another three box sizes ranging from 10×14 mm to 13×19 mm) characters. We applied the same hypotheses as in Experiment 1, that the optimal box size for each set of characters in this experiment is likely to be in the middle range of the three box sizes.

Experiment 4 compared the optimal square box and the optimal rectangular box, results that were obtained from Experiments 1, 2, and 3 for alphanumeric and Kanji & Kana characters. This was because we still expected that the rectangular box would be more suitable for alphanumeric characters and the square box would be more suitable for Hiragana & Katakana characters.

Because Experiment 4 had not given us a clear answer, Experiment 5 was designed to test an additional four sizes of rectangular boxes with sizes between the optimal rectangular box and the optimal square box (i.e., sizes from 7×14 mm to 14×14 mm) for alphanumeric characters. We hypothesized that a rectangular box within the middle range of the four box sizes would be more suitable for alphanumeric characters.

Experiment 6 looked at the impact of user age (younger or older) and user posture (sitting or standing) on handwriting in character input boxes. Four square boxes (with sizes ranging from 10×10 mm to 24×24 mm) with Kanji & Kana characters were tested. We hypothesized that the older group might take much more time to write and they might prefer bigger boxes because of various physiological factors.

Each of these experiments is essential if comprehensive and reliable results regarding the optimal size of input boxes are to be obtained.

3. EXPERIMENT 1: BOX SIZE

The goal of this experiment was to determine the optimal size for handwriting character input boxes. Chinese characters (called "Kanji" in Japanese) mixed with

Japanese Kana (phonetic) symbols, Hiragana & Katakana, and alphanumeric characters were used in the experiments.

3.1. Participants

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

3.2. Apparatus

The hardware used in the experiment was the iPAQ Pocket PC (Hewlett-Packard, Palo Alto, CA) running Microsoft Windows CE 3.0. It weighed about 190 g and was 84 mm (W) × 16 mm (D) × 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++.

3.3. 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 square boxes for testing each of the three kinds of character sets. The sizes of the square boxes tested were as follows:

- 10 × 10 pixels (2 × 2 mm)
- 20 × 20 pixels (5 × 5 mm)
- 40 × 40 pixels (10 × 10 mm)
- 60 × 60 pixels (14 × 14 mm)
- 80 × 80 pixels (19 × 19 mm)

The 19 × 19 mm box is the standard size for the Pocket PC. The other square box sizes decreased in size by 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 19 × 19 mm 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 a 6 × 12 mm (25 × 49 pixels) box for alphanumeric, an 8 × 12 mm (34 × 48 pixels) box for Hiragana & Katakana, and a 9 × 14 mm box (39 × 57 pixels) for Kanji & Kana, as baselines for each of the three character sets. These sizes were established by Ren and Moriya (1995). Thus, for each of the three character sets, we tested six boxes.

Evaluation indices included character recognition rate, the number of protruding strokes, the number of error corrections, average writing time for one character, and questionnaires. The questionnaires involved ease of writing, degree of relaxation, box size preferences, and overall evaluation. The rating scale for the four

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

items is from 1 (*lowest preference*) to 7 (*highest preference*). After finishing the first three subjective evaluation items, the participants were asked to make an overall evaluation for the box sizes used in the experiment. According to the results obtained in the four evaluation items, average subjective ratings were calculated to evaluate the performance of each box size.

3.4. Procedure

First, the outline of the experiment was explained to the participants. To familiarize them with the experimental environment, we set a practice session for each character set and the related box. The participant was asked to input the uppercase and lowercase 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 participant 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 participant were displayed in the upper section of the screen.

For each of the three character sets and each of the six boxes in relation to each character type, the procedure to input a character was as follows: The participant 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 participant finished writing the complete character, the next target character was highlighted in pink. A space was inserted between two characters whenever the participant 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 participant could use this icon to remove any character that he or she wanted to rewrite or correct, for example, when the character that was written by the participant 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 participant would not feel stress caused by having to rewrite a character when the wrong character recognition result was displayed. Because the purpose was to evaluate the optimal box size, we wanted to eliminate any excessive stress.

All participants were in a sitting posture and all held the PDA in his or her hand. After the input of all characters was completed, the participants were 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 participant tested the six box sizes in a different order (partial counterbalancing). A 10-min break was inserted between tests of each box size.

After one round of testing with one character set, the participant would resume the experiment using another character set in a different order. Participants 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 was 5,184 for alphanumeric characters ([26(uppercase English characters) + 26(lowercase English characters) + 20(numbers twice)] × 6[boxes] × 12[participants]), 5,544 for Hiragana & Katakana characters (77[Hiragana & Katakana] × 6[boxes] × 12[participants]), and 5,400 for Kanji & Kana (75[Kanji & Kana] × 6[boxes] × 12[participants]).

During the process 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 participant started to write the character (i.e., the moment that the stylus initially touched the box) to the instant the character was displayed on the upper section of the screen.

3.5. Results

Alphanumeric. No significant difference among the six boxes was found in writing time. Significant differences between the six boxes were found in error corrections, $F(5, 66) = 3.69$, $p < .05$; in the number of protruding strokes, $F(5, 66) = 32.96$, $p < .001$; and in character recognition rate, $F(5, 66) = 6.56$, $p < .001$. The 14 × 14 mm box had the least number of error corrections ($M = 0.50$, see Figure 2). The 6 × 12 mm box had the lowest number of protruding strokes ($M = 0.25$). The number of protruding strokes ranged from the 6 × 12 mm box, 14 × 14 mm box, to 10 × 10 mm box. However, there was no significant difference among these three boxes. Although the rate of recognition for the 10 × 10 mm box ($M = 72.80\%$) was higher than that for the 14 × 14 mm box ($M = 72.69\%$), the post hoc Tukey Honestly

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

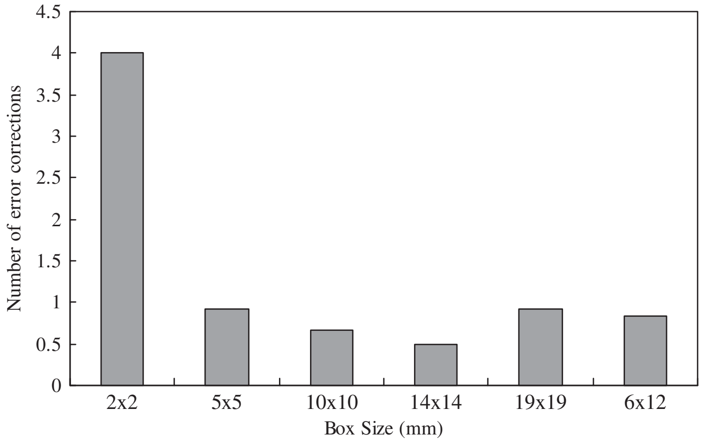

FIGURE 2 The number of error corrections in each of six box sizes for alphanumeric characters in Experiment 1.

Significant Difference (HSD) test showed that there was no significant difference between the two boxes.

We analyzed the average value of the answers given by the participants to four questions. The 14 × 14 mm box received high ratings (M = 6.19) from the questionnaire, $F(5, 18) = 109.04$, $p < .0001$. The post hoc Tukey HSD test showed no significant differences between 14 × 14 mm and each of 10 × 10 mm, and 19 × 19 mm boxes, between 10 × 10 mm and each of 19 × 19 mm, and 6 × 12 mm boxes, and between 19 × 19 mm and 6 × 12 mm boxes; however, a significant difference was found between 14 × 14 and 6 × 12 ($p < .05$).

According to the aforementioned results, we can conclude that the 14 × 14 mm 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 19 × 19 mm box had the lowest number of protruding strokes (M = 0.58) among the six boxes, $F(5, 66) = 23.87$, $p < .001$, there was no significant difference among the 19 × 19 mm, 14 × 14 mm, 8 × 12 mm, and 10 × 10 mm boxes.

A significant difference between the six boxes was found in character recognition rate, $F(5, 66) = 12.72$, $p < .001$. The rates of recognition ranged from the 14 × 14 mm box (M = 82.90%), 8 × 12 mm box (M = 82.79%), 19 × 19 mm box (M = 82.25%), to 10 × 10 mm box (M = 81.28%). However, there was no significant difference among the four boxes.

Moreover, the 14 × 14 mm box received the highest ratings (M = 5.94) from the questionnaire, $F(5, 18) = 188.87$, $p < .0001$. The post hoc Tukey HSD test showed no significant differences between 14 × 14 mm box and each of 10 × 10 mm box, and 8 × 12 mm box, between 10 × 10 mm box and each of 19 × 19 mm box, and 8 × 12 mm box, between 19 × 19 mm box and 8 × 12 mm box; however, a significant difference was found between the 14 × 14 mm box and 19 × 19 mm box ($p < .05$).

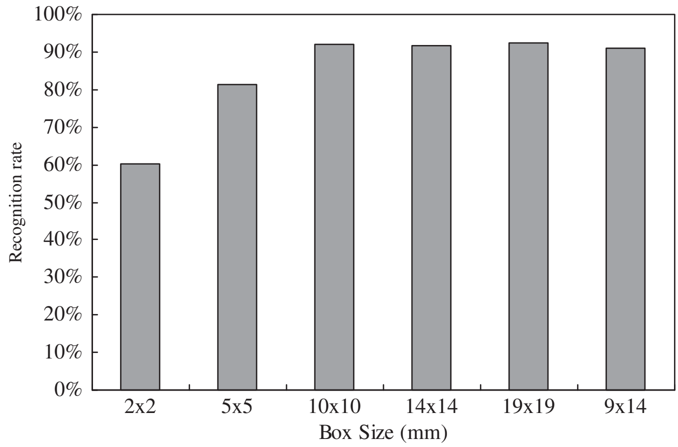

FIGURE 3 The recognition rates in each of six box sizes for Kanji & Kana in Experiment 1.

According to the aforementioned results, we can conclude that the 14 × 14 mm box is the optimal size for Hiragana & Katakana character input.

Kana & Kanji. No significant difference between the six boxes was found in writing time.

A significant difference between the six boxes was found in the number of error corrections, $F(5, 66) = 3.20$, $p < .05$, and in the number of protruding strokes, $F(5, 66) = 25.44$, $p < .001$. The 14 × 14 and 19 × 19 mm boxes had fewer error corrections ($M = 0.42$, 0.33, respectively) and fewer protruding strokes (each with $M = 0.58$) than the other boxes. 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 19 × 19, 10 × 10, and 14 × 14 mm box had higher rates of recognition ($M = 92.56\%$, 92.11%, and 91.67%, respectively) than the other boxes. However, there was no significant difference among these three box sizes.

Moreover, the 14 × 14 mm box received the highest ratings ($M = 5.88$) from the questionnaire, $F(5, 18) = 171.35$, $p < .0001$. The post hoc Tukey HSD test showed no significant differences between each pair of 14 × 14, 10 × 10, 19 × 19, and 10 × 14. Significant differences were found between each of 2 × 2 and 5 × 5, and each of 14 × 14, 10 × 10, 19 × 19, and 9 × 14 ($p < .0001$).

Overall, 14 × 14 and 19 × 19 mm boxes received higher performance and subjective ratings than the other boxes. Because the PDA screen has limited space, we determined that the 14 × 14 mm box is the optimal box for Kana & Kanji character input.

3.6. Discussion

From these results, we can conclude that the optimal box size for the input of all three kinds of character sets is 14 × 14 mm. 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; for example, the 19 × 19 mm box was not as good as the 14 × 14 mm box. This means that there is an optimal box size, and people will feel comfortable and work more efficiently with this size box.

The results were basically consistent with our hypotheses. For example, the smallest box (2 × 2 mm) had the highest number of error corrections and the lowest recognition rate. Some participants stated that they were a little tired when writing in the largest box. The optimal box 14 × 14 mm was almost within the middle range of the six box sizes.

4. EXPERIMENT 2: BOX SHAPE

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

4.1. Participants

Twelve Japanese participants, with an average age of 21.4 years, participated in this experiment (10 male, 2 female; all right-handed). One of them had about 1 year's experience in PDA use. The others had no experience. Some of them had participated in Experiment 1.

4.2. Design

The apparatus and character set used in the experiment were the same as those used in Experiment 1. We designed two character box shapes: rectangular and square. The box sizes for each character set are shown next.

1. Alphanumeric character
   - Square: 10 × 10 (40 × 40 pixels), 12 × 12 (50 × 50 pixels), 14 × 14 (60 × 60 pixels) mm
   - Rectangle (width × height): 6 × 12 (25 × 49 pixels), 9 × 14 (35 × 59 pixels), 11 × 17 (45 × 69 pixels) mm
2. Hiragana & Katakana
   - Square: 12 × 12, 14 × 14, 17 × 17 (70 × 70 pixels) mm
   - Rectangle: 8 × 12 (34 × 48 pixels), 11 × 14 (44 × 58 pixels), 13 × 16 (54 × 68 pixels) mm
3. Kana & Kanji
   - Square: 12 × 12, 14 × 14, 17 × 17 mm
   - Rectangle: 10 × 14 (39 × 57 pixels), 12 × 16 (49 × 68 pixels), 14 × 19 (59 × 78 pixels) mm

The rectangular input boxes, the 6 × 12 mm (for alphanumeric), 8 × 12 mm (for Hiragana & Katakana), and 10 × 14 mm (for Kana & Kanji) boxes, were designed according to the quasi-optimal sizes of the alphanumeric, Kana & Kanji character input boxes, previously determined by Ren and Moriya (1995). 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 14 × 14 mm was the optimal size determined by Experiment 1. The other square boxes were enlarged or reduced in increments of 10 pixels in width and height based on the three boxes.

Evaluation indices were the same as those in Experiment 1.

4.3. Procedure

The experimental procedure was the same as in Experiment 1. Each participant used six different boxes in relation to each character type, and the three character sets were tested in different orders. The participants input 4,464 alphanumeric ([26(uppercase English characters) + 26(lowercase English characters) + 10(numbers)] × 6[boxes] × 12[participants]), 2,952 Hiragana & Katakana (41[Hiragana & Katakana] × 6[boxes] × 12[participants]), and 2,232 Kanji & Kana characters (31[Kanji & Kana] × 6[boxes] × 12[participants]).

4.4. Results

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

Thus, we looked at the results of the questionnaires. With regard to Hiragana & Katakana, we found that there was a significant difference between the six boxes, $F(5, 18) = 9.66$, $p < .001$. The 13 × 16 mm box received the highest ratings ($M = 5.44$), and the next was the 14 × 14 mm box ($M = 5.10$). 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 14 × 19 mm box received the highest ratings from the questionnaire ($M = 5.27$), and the next was 17 × 17 mm ($M = 4.92$), 14 × 14 mm ($M = 4.85$). However, the post hoc analysis showed no significant difference between the three boxes. Nine of the 12 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 14 × 14 mm box is a good choice for the input of Hiragana & Katakana and for Kanji & Kana.

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 11 × 17 mm box received the highest ratings ($M = 5.31$); however, there was no significant difference between each pair of 12 × 12, 14 × 14, 9 × 14, and 11 × 17. Ten of the 12 participants pointed out that they felt it was easier to write alphanumeric characters in these rectangular boxes. Here, we determined that the minimum box 9 × 12 (minimum width × minimum height) and the maximum box 14 × 17 (maximum

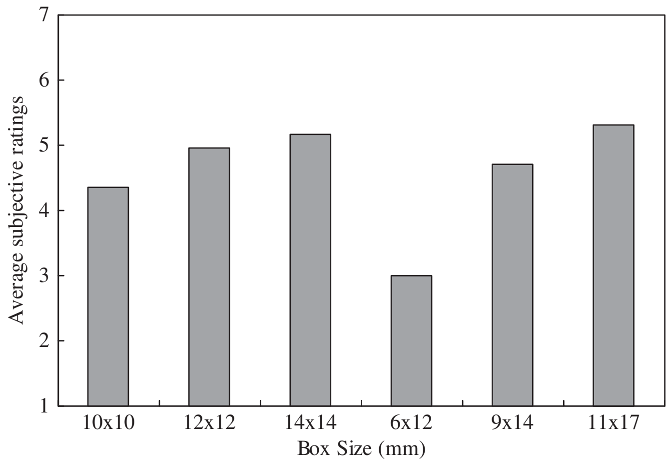

FIGURE 4 Average subjective ratings for alphanumeric characters in Experiment 2 (1 = *lowest preference*, 7 = *highest preference*).

width × maximum height) are the best choice. Thus, we could see that the rectangular boxes ranging from 9 × 12 to 14 × 17 mm were preferred for alphanumeric character writing.

4.5. 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 about 2 to 3 mm 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 (Ren & Moriya, 1995).

Through the experiment on box shape, we noticed that most participants 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 because the aspect ratios of the boxes and the characters are generally the same.

On the other hand, most participants 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.

The results were also basically consistent with our original hypotheses. However, the optimal size for alphanumeric character writing included a large range (from 9 × 12 to 14 × 17 mm) 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 experimental results depend on the aspect ratio is still not clear.

5. EXPERIMENT 3: RECTANGULAR BOX SIZE

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

5.1. Participants

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

5.2. Design

The apparatus used in the experiment was 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 next.

1. Alphanumeric characters with the same ratio:
   - 25 × 49 pixels (6 × 12 mm)
   - 31 × 60 pixels (7 × 14 mm)
   - 36 × 71 pixels (9 × 17 mm)
2. Kana & Kanji with the same ratio:
   - 39 × 57 pixels (10 × 14 mm)
   - 47 × 68 pixels (11 × 16 mm)
   - 54 × 79 pixels (13 × 19 mm)

The rectangular input boxes, 6 × 12 mm (for alphanumeric) and 10 × 14 mm (for Kana & Kanji) were designed according to the quasi-optimal sizes of the alphanumeric, Kana & Kanji character input boxes previously determined by Ren and Moriya (1995). We used the aspect ratios of the boxes (i.e., height/width) as the baseline. The other rectangular boxes were enlarged in 11-pixels increments in height based on the two boxes. The widths were based on the two baseline ratios.

5.3. Procedure

The experimental procedure and evaluation indices were the same as in Experiment 1. The difference is that we asked the participants to input the target character into the boxes "as quickly and clearly as possible." Thus, besides the number of

[3]We omitted Hiragana & Katakana in this experiment because the result for Hiragana & Katakana was the same as Kanji & Kana in Experiments 1 and 2, and it is included in Kanji & Kana; we also wanted to reduce the experimental load.

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. Pen movement time was measured as the moment from when the participant finished writing one character to the moment when the participant started to write the next character.

The total number of characters tested in the experiment was 2,232 for alphanumeric characters ([26(uppercase English characters) + 26(lowercase English characters) + 10(numbers once)] × 3[boxes] × 12[participants]) and 2,484 for Kana & Kanji (69[Kana & Kanji] × 3[boxes] × 12[participants]).

5.4. 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 9 × 17 mm box received the highest ratings ($M = 5.0$), and the next was 7 × 14 mm ($M = 4.96$). However, the post hoc analysis showed no significant difference between the two boxes. After the questionnaires were completed, the participants were asked to put the box sizes in their order of preference (i.e., from best to worst). The majority of the participants preferred the 7 × 14 mm box for alphanumeric input. According to the aforementioned results, we can conclude that the 7 × 14 mm 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 11 × 16 mm box received the highest ratings ($M = 4.81$), and the next was 13 × 19 mm ($M = 4.60$). However, the post hoc analysis showed no significant difference between the two boxes. Moreover, the majority of the participants (five eighths) preferred the 11 × 16 mm box for Kana & Kanji. They said that it was easier to write Kanji & Kana characters in this box. Therefore, we concluded that the 11 × 16 mm box was the optimal box size for Kana & Kanji character input.

5.5. Discussion

The results showed that there was no difference between the three boxes for each of two kinds of character. 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 (1995) and the sizes of the boxes tested were not so different. Concerning the questionnaire and the participants' comments, the rectangular optimal sizes for each of two kinds of characters were determined to be 7 × 14 mm for alphanumeric and 11 × 16 mm for Kana & Kanji. The results were basically consistent with our original hypotheses. The participants preferred the box within the middle range of all the box sizes because it was easier to write characters in that box.

6. EXPERIMENT 4: RECTANGULAR VERSUS 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., 14 × 14 mm box), which was determined by Experiments 1 and 2.

6.1. Participants

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

6.2. Design

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

The sizes for each character set are shown next.

1. Alphanumeric characters
   - Square: 60 × 60 pixels (14 × 14 mm)
   - Rectangle: 31 × 60 pixels (7 × 14 mm)
2. Kana & Kanji
   - Square: 60 × 60 pixels
   - Rectangle: 47 × 68 pixels (11 × 16 mm)

The rectangular input boxes, 7 × 14 mm for alphanumeric and 11 × 16 mm for Kana & Kanji, were the optimal sizes determined by Experiment 3. The square input box, 14 × 14 mm, was chosen according to the results of Experiments 1 and 2. The participants input a total of 1,488 alphanumeric and 1,656 Kana & Kanji characters.

6.3. Results

Alphanumeric. No significant differences were found between the two boxes in each of the evaluation indices. Regarding the subjective ratings, the 14 × 14 mm box received high ratings ($M = 5.31$), $F(1, 6) = 12.63$, $p < .05$. After the questionnaires were completed, the participants were asked to put the box sizes in their order of preference, that is, from best to worst. However, half of the participants commented that they preferred the rectangular box for writing alphanumeric characters. The contradiction between the results of questionnaires 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.

Kana & Kanji. The experimental data showed no significant differences between the two boxes in each of the evaluation indices, or the questionnaire. However, the majority of the participants (three fourths) commented that they preferred to write Kana & Kanji in 14 × 14 mm square box.

6.4. Discussion

The participants preferred the 14 × 14 mm box. The reason may be that most Kanji are square in shape. This is consistent with our original hypotheses. However, with reference to alphanumeric input, the results were not very consistent with our hypotheses. There was some contradiction between the participants' comments and the results of questionnaires, that is, half of the participants preferred the rectangular box for writing alphanumeric characters; however, the 14 × 14 mm square box received higher ratings than the rectangular box. The contradiction between the results of questionnaires 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.

7. EXPERIMENT 5: TEST OF ADDITIONAL RECTANGULAR BOX SIZES

7.1. Participants

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

7.2. Design

The apparatus, 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 as shown:

- 31 × 60 pixels (7 × 14 mm)
- 40 × 60 pixels (10 × 14 mm)
- 50 × 60 pixels (12 × 14 mm)
- 60 × 60 pixels (14 × 14 mm)

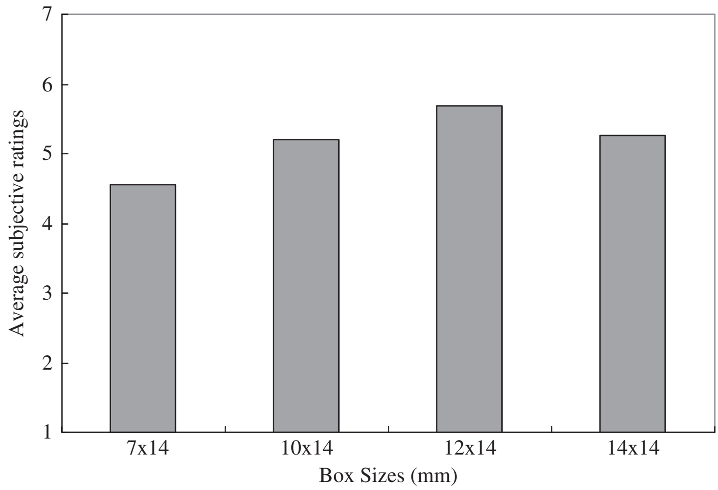

FIGURE 5 Subjective results for alphanumeric characters in Experiment 5 (1 = *lowest preference*, 7 = *highest preference*).

The 7 × 14 mm and 14 × 14 mm boxes were chosen according to Experiment 4. The participants input 3,456 alphanumeric characters.

7.3. Results and Discussion

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 12 × 14 mm box received the highest ratings ($M = 5.69$), $F(3, 12) = 10.28$, $p < .01$. Furthermore, more than half of the participants commented that they felt that it was easier to write alphanumeric characters in the 12 × 14 mm box than in any other boxes and they didn't like the square box or the smaller rectangular boxes. The results were consistent with our original hypotheses.

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. This is probably because most alphanumeric characters are rectangular in shape. Thus, we concluded that the 12 × 14 mm rectangular box is the optimal box for alphanumeric character input on PDAs.

8. EXPERIMENT 6: USER AGES AND USER POSTURES

The results of Experiments 1 to 5 revealed the optimal sizes of boxes. However, these experiments did not consider the effect of user age (younger or older) or user posture (sitting or standing) on the input of handwriting characters into the boxes. Whether the results are affected by user age or posture was still not clear. Thus, we sought to determine the optimal box size with consideration being given to user age and posture when handwriting on PDAs.

8.1. Participants

Two age groups (younger and older) were recruited to participate in this experiment. For the younger group, 8 Chinese participants (who also had a high level of proficiency in writing Japanese) and 4 Japanese participants (average age = 26.8, 11 male, 1 female; all right-handed) were tested. None of the younger participants had any experience in using PDAs and they had not been involved in Experiments 1 to 5. For the older group, 12 Japanese participants (average age = 66.2, 4 male, 8 female; all right-handed) who had never used PDAs and had not been involved in Experiments 1 to 5 were recruited.

8.2. Design

The apparatus, experimental procedure and evaluation indices used in the experiment were the same as in Experiment 3. We only used Kana & Kanji because the older participants could not understand English very well and we didn't want to increase their mental and physical burdens. The box sizes tested were as follows:

- 40×40 pixels (10×10 mm)
- 60×60 pixels (14×14 mm)
- 80×80 pixels (19×19 mm)
- 100×100 pixels (24×24 mm)[4]

The 14×14 mm input box for Kana & Kanji was the optimal size determined by Experiments 1 to 4. The other boxes were changed by increments of 20 pixels. The experimental procedure and evaluation indices were the same as in Experiment 3. The difference was that all subjects conducted the experiment in two postures (i.e., sitting and standing postures). The four box sizes and the two postures were balanced by a Latin Square arrangement between these participants.

The total numbers tested by the experiment were 3,648 for Kana & Kanji (19 [Kana & Kanji] × 4 [boxes] × [12 (younger) + 12 (older)] [participants] × 2 [postures]).

8.3. Results and Discussion

Older user group. For the older user group, no significant difference between the four boxes was found in terms of pen movement times or the number of error corrections in each of the two postures. No significant differences were found between the two postures in each of the evaluation indices.

Significant differences between the four boxes were found in the number of protruding strokes, $F(3, 33) = 33.79$, $p < .001$; in character recognition rate,

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

$F(3, 33) = 7.77$, $p < .001$; in writing time, $F(3, 33) = 7.64$, $p = .001$; and the average subjective rating, $F(3, 33) = 9.91$, $p < .001$. The numbers of protruding strokes for 10 × 10 mm, 14 × 14 mm, 19 × 19 mm, and 24 × 24 mm boxes were, respectively, 5.29, 1.5, 1.5, and 0.54. The post hoc Tukey HSD test showed that there was no significant difference between the 14 × 14 mm and 19 × 19 mm boxes. The 10 × 10 mm box had the highest number of protruding strokes. Significant differences were found between the 14 × 14 mm box and 10 × 10 mm box ($p < .001$) and between the 14 × 14 mm box and 24 × 24 mm box ($p = .006$). The character recognition rate ranged from the 10 × 10 mm box (M = 75.66%), 14 × 14 mm box (M = 80.48%), 19 × 19 mm box (M = 84.43%), to 24 × 24 mm box (M = 84.43%). However, the post hoc Tukey HSD test showed no significant differences between 14 × 14 mm box and each of the 10 × 10 mm, 19 × 19 mm, and 24 × 24 mm boxes. The writing times for the 10 × 10 mm, 14 × 14 mm, 19 × 19 mm, and 24 × 24 mm boxes were, respectively, 253.6 sec, 277.6 sec, 288.5 sec, and 309.9 sec. However, there was no significant difference between the 14 × 14 mm box and each of the 10 × 10 mm and 19 × 19 mm boxes.

The 19 × 19 mm box received high ratings (M = 5.47) from the questionnaires. However, there was no significant difference between the 14 × 14 mm box and the 19 × 19 mm box. The 10 × 10 mm box received low ratings (M = 3.56) from the questionnaires. A significant difference was found between the 14 × 14 mm box and the 10 × 10 mm box ($p < .001$).

Overall, 14 × 14 mm and 19 × 19 mm boxes received higher performance and subjective ratings than the other boxes. Because the PDA screen has limited space, we determined that the 14 × 14 mm box was the optimal character box size for the older user group in both sitting and standing postures.

Younger user group. For the younger user group, no significant difference between the four boxes was found in terms of character recognition rate, the number of error corrections, or pen movement times in each of the two postures. No significant differences were found between the two postures in each of the evaluation indices.

Significant differences between the four boxes were found in the number of protruding strokes, $F(3, 33) = 23.99$, $p < .001$; in writing time, $F(3, 33) = 4.63$, $p = .008$; and the average subjective rating, $F(3, 33) = 21.79$, $p < .001$. The numbers of protruding strokes for the 10 × 10 mm, 14 × 14 mm, 19 × 19 mm, and 24 × 24 mm boxes were respectively 2.92, 1.25, 0.63 and 0.29. The post hoc Tukey HSD test showed that there was no significant difference between the 19 × 19 mm and 24 × 24 mm boxes. The 10 × 10 mm box had the highest number of protruding strokes of all the box sizes. The writing times for the 10 × 10 mm, 14 × 14 mm, 19 × 19 mm, and 24 × 24 mm boxes were, respectively, 215.1 sec, 236.1 sec, 242.4 sec, and 249.1 sec. However, there were no significant differences between the 14 × 14 mm box and each of the 24 × 24 mm boxes and 19 × 19 mm boxes.

The 19 × 19 mm box received the highest ratings (M = 5.97) from the questionnaires. However, there were no significant differences between the 19 × 19 mm box and the 24 × 24 mm box, the 14 × 14 mm box, and the 24 × 24 mm box. The 10 × 10 mm box received the lowest ratings (M = 2.94) from the questionnaires.

Significant differences were found between the 10×10 mm and each of the 14×14 mm, the 19×19 mm, and the 24×24 mm boxes (all *p*s < .001).

Overall, the 14×14 mm and the 19×19 mm boxes received higher performance and subjective ratings than the other boxes. Because the PDA screen has limited space, we determined that the 14×14 mm box was the optimal character box size for the younger user group in both sitting and standing postures.

Based on the aforementioned results, we concluded that the optimal character box size for the older group was the same as that for the younger group. The results differed from our original hypotheses. The older group didn't like the bigger boxes. It was known that the normal effects of aging include some decline in cognitive, perceptual, and motor abilities (Salthouse, 1991). 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 and the younger group, $F(1, 22) = 4.75$, $p = .04$. The older users wrote characters more slowly than the younger users. Furthermore, there was a significant difference in the number of protruding strokes between the two groups, $F(1, 22) = 4.99$, $p = .036$; the older users produced more protruding strokes than the younger users. These differences between the two groups were affected by bodily factors, which were consistent with our hypotheses. This agrees with Salthouse (1991).

9. GENERAL DISCUSSION AND CONCLUSIONS

Six experiments have been conducted to investigate the optimal size of handwriting character input boxes on PDAs. We determined the optimal shape and size of character input boxes for various character sets which allow users to input handwriting comfortably and efficiently.

Experiment 1 examined the effect of square boxes on input performance and produced the result that the optimal box size is 14×14 mm. In Experiment 2, we asked whether the shape (square or rectangular with different aspect ratios) of the input boxes has any effect when writing characters on a PDA screen and determined that, in fact, a range of rectangular boxes is best for alphanumeric input. Experiment 3 examined and determined the optimal rectangular box size using the same aspect ratio. Experiment 4 compared the results of Experiment 3 with the optimal square box (i.e., 14×14 mm box) which was determined by Experiments 1 and 2. Because some participants commented that they wanted to try some box sizes between the box sizes tested in Experiment 4, we performed a further experiment described in Experiment 5 to test additional rectangular boxes. The results of Experiments 1 to 5 revealed the optimal sizes of boxes. However, these experiments did not consider the user age groups (younger and older) and user postures (sitting and standing) while inputting handwriting characters into the boxes. Whether the result depends on the user ages and user postures was still not clear. Thus, Experiment 6 investigated these questions, making comparisons between younger and older users, and between sitting and standing postures. We concluded that the optimal box size of 14×14 mm for both user groups and user postures is best.

Based on the results of these experiments, we determined the optimal sizes for the respective character sets as follows:

- Alphanumeric: 12 × 14 mm (rectangular)
- Kanji & Kana: 14 × 14 mm (square)
- Hiragana & Katakana: 14 × 14 mm (square)

Regarding shape, the principle appears to be as follows: It is more comfortable to input characters into boxes that 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 because of the far greater number of strokes appearing in most Kanji characters. When writing alphanumeric characters, participants tend to try to use the whole area of the square, thus creating a conflict in 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 handwriting character input boxes, the standard size of handwriting input boxes for Pocket PCs is 19 × 19 mm; the Palm OS input box is about 17 × 19 mm. However, we determined that the optimal box size is 12 × 14 (alphanumeric) –14 × 14 (Katakana & Hiragana, Kanji & Kana). The differences between the optimal size and Pocket PC standard size and between the optimal size and Palm OS box size are around 7 × 5 – 5 × 5 mm, 5 × 5 – 2 × 5 mm, 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.

We conducted a number of significant stand alone experiments to establish various critical parameters regarding size and shape. We then performed more tests so that the original test results could be confirmed or adjusted in relation to each other and in relation to user age and posture factors. This approach was necessary for the following reasons. First, the physical environment could not permit the performance of only one large-scale experiment. A number of distinct experiments were necessary to achieve our goal because the tests included so many issues, for example, user group, box size, box shape, user postures, and so on. Second, quantitative observations can be feedback to the iterative design–evaluation–design cycle. We could not see all processes *before* we just did them. Hypotheses on novel investigations can only be validated by empirical data. Overall, the integration of these valuable experiments provided comprehensive and intensive research on the optimal box size and verified the rigor and reliability of the optimal box size.

We varied the essential parameters, but we omitted the learning effect to simplify our experimental design because two supplementary experiments (based on age, 12 younger participants performing the experiment in six blocks and 12 older participants performing the experiment in three blocks), which were similar to the task and design of Experiment 6, revealed no significant learning effect. Because of the minor significance of the point, we do not report it comprehensively in this article. Besides, there is seldom a significant effect on the dependant variables among the tested boxes. This is because very large and very small candidate boxes are excluded from our design to reduce the number of trials each participant performs.

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 participants including younger and older adult users, as well as users who had never used a PDA; we gave consideration to the effects of sitting and standing postures as well as to the learning effect. Furthermore, in our experiments, participants input several thousands of commonly used characters including all English 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, that is, 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 input 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.

REFERENCES

Kato, T., Ren, X., Sakai, Y., Machi, Y. (2003). The optimal sizes of input square for the pen-input characters on PDAs. *Proceedings of HCI International*, *2*, 686–690.

MacKenzie, I. S., Nonnecke, B., Riddersma, S., McQueen, C., & Meltz, M. (1994). Alphanumeric entry on pen-based computers. *International Journal of Human-Computer Studies*, *41*, 775–792.

MacKenzie, I. S., & Soukoreff, R. W. (2002). Text entry for mobile computing: Models and methods, theory and practice. *Human-Computer Interaction*, *17*(2), 147–198.

Ren, X., & Moriya, S. (1995). The minimal sizes and the quasi-optimal sizes for the input square during pen-input of characters. *Journal of Information Processing*, *36*(3), 654–657.

Salthouse, T. A. (1991). *Theoretical perspectives on cognitive aging*. Hillsdale, NJ: Erlbaum.

Sears, A., Revis, D., Swatski, J., Crittenden R., & Shneiderman B. (1993). Investigating touchscreen typing: The effect of keyboard size on typing speed. *Behaviour and Information Technology*, *12*(1), 17–22.

Soukoreff, W., & MacKenzie, I. S. (1995). Theoretical upper and lower bounds on typing speed using a stylus and soft keyboard. *Behaviour and Information Technology*, *14*(6), 370–379.

Tanaka, H., & Ishigaki, K. (2001). Practicality of handwriting Japanese input interface with and without a writing frame. *Proceedings of HCI International 2001*, *1*, 435–439.

Wang, X., Li, J., Ao, X., Wang, G., & Dai, G. (2006). Multimodal error correction for continuous handwriting recognition in pen-based user interfaces, *Proceedings of IUI'06*, 324–326.

Wobbrock, J. O., Myers, B. A., & Chau, D. H. (2006). In-stroke word completion. *Proceedings of UIST'06*, 333–336.

Wobbrock, J. O., Myers, B. A., & Kembel, J. A. (2003). EdgeWrite: A stylus-based text entry method designed for high accuracy and stability of motion. *Proceedings of UIST'03*, 61–70.

Zhai, S., & Kristensson, P. (2003). Shorthand writing on stylus keyboard. *Proceedings of CHI'03*, 97–104.