The impact of candidate display styles for Japanese and Chinese characters on input efficiency

Minghui Sun\textsuperscript{a,b}, Xiangshi Ren\textsuperscript{a,*}, Shumin Zhai\textsuperscript{c}, Feng Wang\textsuperscript{d}

\textsuperscript{a}School of Information, Kochi University of Technology, Japan
\textsuperscript{b}Department of Computer Science and Technology, Jilin University, China
\textsuperscript{c}Google Research, Mountain View, CA 94043, USA
\textsuperscript{d}Department of Computer Science and Technology, Kunming University of Science and Technology, China

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Abstract

Entering non-alphabetic text for languages such as Japanese and Chinese into a computer typically consists of typing Roman character-based phonemes and selecting the intended Japanese or Chinese character from a list of homophonic candidates. This paper presents a study of four candidate display styles. Three of them, Vertical, Horizontal, and Compact-Horizontal, are used in commercial products. The fourth style, Matrix, is novel. The candidate display style is studied in conjunction with various manual selection devices including Mouse, Numeric Keys, Spacebar, Cursor Key, and Numeric Keypad. Results show that a great deal of time is taken to choose the correct character in both Chinese and Japanese input. The candidate display style affects both input efficiency and subjective preference. Results also show that the Compact-Horizontal display style outperforms other display styles with a normal keyboard but the Matrix display style is the most efficient when used with a Numeric Keypad due to stimulus–response compatibility and the movement efficiency of such a design.

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1. Introduction

Despite calls for greater emphasis on and sensitivity to language and culture-specific aspects of human-computer interaction (e.g., Shneiderman, 1992; Hamzah et al., 2006), most of the computer interfaces used in different parts of the world today are simple conversions from English. There are many interesting and challenging language and culture-specific HCI research problems that warrant in depth examination. Text input in non-alphabetical languages, such as Japanese and Chinese, is one of these challenges with untested potential.

The most commonly used solution to non-alphabet text input, both in Japanese and Chinese, is to use a Roman alphabet-based phonetic system, such as romaji in Japanese and pinyin in Chinese, as an intermediary. Unfortunately, in these languages the mapping from a phonetic spelling to a written character is not one to one. The user therefore has to select the intended character from a list of homophonic choices. In a study of Chinese input, Wang et al. (2001) found that choice reaction alone consumed 36 of the total input time in their experiment. The same issue may exist in Japanese text input. To type Japanese, the user has to first type a set of Roman letters which correspond to a phonetic Japanese kana character. Kanji characters are Chinese characters adopted into the Japanese written language. When a Kanji character is wanted, the user usually presses the spacebar to convert the kana character to the most likely Kanji character. If this is not the intended Kanji character, one has to press the spacebar again to bring up a list of homophonic candidates from which the correct character may then be chosen.
More and more new input methods are being proposed. The current input methods support text entry by blind typing (Starner, 2004), intelligent combination of several words, context-based character prediction (Mays et al., 1990), stroke-based input scheme (Hsu, 1991), non-desktop text input (Wigdor and Balakrishnan, 2004; Go et al., 2008; Perlin, 1998; MacKenzie and Zhang, 1999) and so on. However, visual scanning (Pelphrey et al., 2002; Wainwright, 1999) of language character screens, which is a natural human ability to catch relevant and interesting information by human vision, is still an emerging text entry research topic. Many researchers have studied the visual search of language character screens with text flowing in different directions. Landauer and Nachbar (1985) investigated the effect of the breadth, depth and width of menu trees on selection with a touch screen. Freeman (1980) measured the visual acuity of random characters from different languages with horizontal rows and vertical columns. The results showed that people could see random English characters better with horizontal rows than with vertical columns. Backs et al. (1987) concluded that the orientation effect of horizontal and vertical screen menus in English had a significant impact on search time and operator search time was shorter for vertical menus than for horizontal menus. Shih and Goonetilleke (1998) investigated the differences and similarities in visual search of Chinese characters among Hong Kong Chinese, Mainland Chinese and Chinese people who cannot read Chinese text. They found that word complexity did not affect accuracy or search time significantly and a horizontal search pattern may be appropriate for Chinese. Ren et al. (2003) investigated the effect of candidate display styles only in Japanese input. They did not explore the other non-alphabet languages (Huang, 1985), such as Chinese (Chen, 1997; Peng, 1982). In this paper, we include both sentence candidates for Japanese input and Chinese single word candidates. We believe that our work is important not only for Chinese and Japanese text entry but also for languages that use similar input methods.

An intriguing user interface design issue is how to display homophonic multiple Chinese or Japanese candidates. Their display format may impact not only visual search time and behavior, but also the time it takes to select the correct character from a candidate list. In this study, we attempt to define and clarify important basic principles in this particular field of HCI literature.

Fig. 1 shows three examples of existing display styles. From a list of candidates the user can select the intended Kanji character by various input methods such as pressing the corresponding numeric keys, the spacebar, the cursor key, or the mouse button.

The different candidate display styles may impact the user’s experience and performance in a few intertwined ways. First, they may change the user’s visual scanning and reaction time. In the context of software menu displays in Chinese, Shih and Goonetilleke (1998) found that menu flow or menu orientation indeed had an impact on user reaction time. Second, the

Fig. 1. Different existing display styles in Chinese and Japanese input. (a) Horizontal display style for Chinese input, (b) Horizontal display style for Japanese input and (c) Vertical display style for Japanese input.

The user’s candidate choice selection time may also depend on the manual selection method used, for example, Mouse, Spacebar, Cursor Key, Numeric Keys and so on. Third, the relationship between display and input methods may differ, particularly in terms of spatial S-R (stimulus–response) compatibility (Fitts and Seeger, 1953). We investigate these issues here in an empirical study of character input. There are three within-subject experiments in this study. Because the number of input characters may affect the results, we considered not only single Japanese character input in Experiment 1, but also the input of a set of Japanese characters in Experiment 2. We also investigate Chinese character input to test whether there is a difference between Japanese and Chinese by comparing Experiment 1 with Experiment 3. The following sections detail three experiments in our study.

2. Experiment 1: Single Japanese character input

2.1. Experimental design

2.1.1. Experimental environment

The monitor was a 17-inch TFT display made by Iiyama. The resolution was 1280 pixels × 1024 pixels. A two-button mouse and a common keyboard named 108 Japanese keyboard were used in the experiment. The CPU was a Pentium3 (1 GHz) from Intel and the RAM memory was 256 MB. The OS was Microsoft Windows 2000 Professional. The Japanese conversion software was Microsoft IME-2000, and the dictionary in the experiment was the dictionary supplied with the default system. The learning function of the dictionary was set to “off” so that the order of candidate characters would be the same for each subject.

2.1.2. Experimental task

The experimental task used in the study was single Kanji character input. In each cycle of the multi-step task, a target Kanji character and its Kana were first displayed on
the screen. Second, the subject entered Kana by typing its corresponding Roman letters via the keyboard. Third, the Katakana or hiragana was converted to a Kanji character by pressing the spacebar. If the resulting Kanji character was not the intended character, the subject pressed the spacebar once again, and a list of candidates, which was presented in one of the display styles described in Section 2.1.3, was displayed. Fourth, if the intended character was not in the list, the subject visually scanned and located the intended character by repeatedly pressing the page down key, the spacebar or the cursor key, or by mouse clicking on the scrollbar on the display to bring up the next set of candidates, until the intended character was found. Finally, the subject selected the target Kanji character by pressing the enter key, the numeric keys, or the mouse button.

2.1.3. Display styles

We studied four display styles, all shown in Fig. 2. Vertical and Compact Horizontal are commonly seen in Japanese input applications. In both cases, the numeric labels of the candidates are laid out in a column or row which is separate from the candidates themselves. The first display method, which we defined as Horizontal display style, lays the candidates together with their numeric labels in a single row. This is commonly seen in Chinese software. The Compact Vertical method, which makes a quarter turn clockwise from the Horizontal display menu, lays the candidates together with their numeric labels in a single column. The Compact Vertical method is not considered in our study because it has not been applied in any software. The idea of taking advantage of the spatial locations of Numeric Keys (e.g., the ZoneZoom Project (Robbins et al., 2004; Perlman and Sherwin, 1988) or grid-based interaction (Rosenbaum and Schumann, 2005) in a keypad to facilitate choice reaction tasks has been widely explored in mobile computing. However, little study has been done on investigating the display style in desktop input. Therefore, the fourth display style is a novel display style that we designed for this study. As shown in Fig. 2(d), the candidates in our design are laid in a 3 by 3 Matrix without numeric labels. Instead, candidates in the Matrix method are selected by the corresponding 3 \times 3 keys in the numeric keypad of the full keyboard (shown in Fig. 3). For example, the top left character will be selected if the user presses the number 7 button. There are several key motivations to such a design. First, this method is fully S–R compatible; the display and input control keys share exactly the same layout. Second, unlike the Numeric Keys on the top of the keyboard, the Numeric Keypad on the side can be reliably touch-typed, as is common in accounting practices. The difficulty of touch-typing keys calls for visual attention shifts from the screen to the keyboard: this is a major problem in Japanese and Chinese input (Wang et al., 2001).

In all four cases the size of each box, a character or a number, was held constant at 0.7 cm by 0.7 cm.

2.1.4. Selection methods

To select the target from among many candidates, the subject was asked to use one of the following methods.

1. Spacebar method: the selection cursor shifted along the candidate list when the spacebar was pressed. A target character was selected by pressing the enter key.

Fig. 2. Four display styles tested in single Japanese character input. (a) Horizontal display style, (b) compact Horizontal display style, (c) Vertical display style and (d) Matrix display style.

Fig. 3. Numeric Keypad.
2. Cursor Key method: the subject controlled the cursor key via the physical keyboard to shift through the candidate list. When the target character was highlighted, the subject pressed the enter key to input it.
3. Numeric Keys method: Selection of a target character was made when a corresponding numeric key, either in the top row or at the side of the keyboard, was pressed.
4. Mouse method: the mouse cursor was moved to the target candidate. Selection was completed by a mouse click.
5. Unrestricted method: the subject could choose any of the above input methods freely.

2.1.5. Subjects
Twelve Japanese subjects (11 males and 1 female) participated in the experiment. Their average age was 21.4 years. Subjects had an average of 3 years previous experience in Japanese typing. All had experience using the Vertical display style and four had experience using the Horizontal display style.

2.1.6. Experiment design and procedure
The experimental task was first explained to the subjects. Each subject was given ten practice trials with each input method and display style. They were asked to have a rest between trials.

Tests consisted of typing 20 Kanji characters with each display style and input method. The order of the display styles was randomized. A within subject design was used. With Matrix style, the target Kanji character was selected via the Numeric Keypad alone. With other styles, the subjects were asked to use input methods whose order was designed with a Latin Square pattern across all the subjects, in order to counterbalance the different combinations of conditions.

These 20 Kanji characters with 40 Hiragana or Katakana letters took 63 Roman letters to specify. The number of page up and page down operations, which was the process of typing a character, depended on the number of candidates displayed per page. An average of two page-down operations was needed for each of 9 candidates per page.

Fig. 4. The whole process of inputting a Japanese Kanji character. \( t_1 \) (target display time): from the target character being displayed to the subject’s first keystroke. \( t_2 \) (time for typing): from the first keystroke to the last keystroke for typing the Roman letters. \( t_3 \) (Kanji display time): from finishing the last keystroke to displaying a Kanji character candidate list (including the Kana conversion processes). \( t_4 \) (choice reaction time): from displaying a candidate list to choosing a target character (Kanji character) successfully. \( t_5 \) (time for input again): inputting the Hiragana or Katakana once again after deleting the false character if a wrong character was chosen.
The total number of characters typed by each subject was: 4 display styles × 10 practice characters + (3 display styles × 5 input methods + 1 display style × 1 input method) × 20 characters = 360 characters.

2.2. Results

2.2.1. Time measures

The total typing time, from the moment a target Kanji character was displayed to the moment the final Kanji character was selected, was recorded as 5 segments which are shown in Fig. 4(a)–(e).

The total typing time as defined above also incorporated error rate calculated from the number of incorrect character entries because as incorrect characters were entered more time was spent in correcting them (t5). As shown in Fig. 5, t1–t5 together constituted only a small part of the entire operation time. Since these components did not have much to do with the candidate display style, not surprisingly there was no significant difference in t1, t2, t3 and t5 between the three styles in each input method. Choice reaction time (t4) was the most time consuming in each of the four display styles: 69.1 in the Matrix style, 73.29 in Compact-Horizontal style, 76.56 in the Horizontal style, and 76.64 in the Vertical style. Although the experiment setup in Wang et al. (2001) is word based, choice reaction and selection in this study took a greater portion of the entire operation time than in the study of Chinese input reported by Wang et al. (2001). This was probably due to the greater number of candidate choices having the same Roman spelling in Japanese. Hence it is important to analyse the time taken for choosing the right character in more detail.

Fig. 6 shows t4 (choice reaction time) in different input methods and display styles. First we examined the differences among the three existing display styles: Compact-Horizontal, Horizontal, and Vertical. When using the Mouse, there was a significant effect of display styles on the time take to choose the correct target (F(2,33) = 3.67, p < 0.05). The Compact-Horizontal display style was faster than the Vertical and Horizontal display styles, but the difference between the Compact-Horizontal display style and the Vertical display style was not significant. When using the Cursor Key, there was a significant effect of display styles on target choice time (F(2,33) = 4.62, p < 0.05). The Compact-Horizontal style was faster than the Vertical and Horizontal display styles. With the rest of the selection methods (unrestricted, Spacebar, Numeric Keys), the display effect was not significant. Overall, the Compact-Horizontal and Vertical styles were superior to the Horizontal style. The crisscross between candidates and numbers in Horizontal
style may increase the workload when choosing the target. Compared with Vertical and Compact-Horizontal styles, the design of the Horizontal style increases the time of visual search because of the longer search distance, especially when the user needs to reveal many candidate lists to find the actual target character.

Next we compared the new Matrix style with the other three display styles in each of the input methods in t4 (choice reaction time). The Matrix style was faster than the other three display styles; when using the Cursor Keys, there was significant effect from display styles on target choice time ($F(3,44) = 5.77, p < 0.05$); when using the Spacebar, there was a significant effect from display styles on target choice time ($F(3,44) = 3.85, p < 0.05$); and when using the Mouse, there was significant effect from display styles on target choice time ($F(3,44) = 4.45, p < 0.05$). However, there was no significant difference between the Matrix and Compact-Horizontal display styles with the Cursor Key, the Spacebar or the Mouse. Furthermore, there were no significant differences among the four display styles when using either the unrestricted method or the Numeric Keys input method.

2.2.2. Subjective evaluation

After finishing the tests, the participants’ subjective reactions (Fig. 7) were recorded. Here are two conclusions: eight participants preferred the Compact-Horizontal style over the Vertical or Horizontal styles. They mentioned that the Numeric Keys were horizontally arranged. It was comfortable to input characters where the visual display style and the physical keyboard where the same in their layout. This showed that most of the users emphasized the need for spatial S–R compatibility. Over half of the subjects preferred the Matrix style with the keypad input method. They reported that the Matrix style corresponded to the Numeric Keypad.

2.3. Discussion

The anatomical analysis of single Kanji character input reveals a major bottleneck in Japanese input. We found that, similar to Chinese input (Wang et al., 2001), choice reaction and selection (t4) in Japanese input takes a great deal of time. This process is also error prone with some input methods. For example, with the Numeric Keys input method, errors were occasionally made when the user pressed both the target number and the number key next to it, indicating difficulty in touch typing with the numeric keys on the top row of the keyboard.

Our study also found that the display styles of candidate lists significantly affected Japanese text input. The results showed that Compact-Horizontal and Vertical were more efficient overall than the Horizontal display style. Although no significant difference was found between the Compact-Horizontal and the Vertical display styles, the subjects preferred to use the Compact-Horizontal display style. Overall, we concluded that the Compact-Horizontal display style is a good design choice.

The novel Matrix style of selection via the Numeric Keypad is faster than the other three display styles (selection by the Cursor Keys, the Spacebar, or the Mouse). The Compact-Horizontal display style was close to the Matrix display style in performance, but over half of the subjects preferred the Matrix style. Taken together, the Matrix display style can be regarded as the best choice. The drawback of the Matrix display is that numeric keypads spatially compatible with the Matrix display are not available in most laptop computers. There are, nevertheless, some laptop models with keypad potentiality. This is somewhat achieved through a keypad activating function built into the system, and also through an add-on external keypad option.

3. Experiment 2: Japanese character-set input

Experiment 1 examined single Kanji character input. This experiment expands the scope of the investigation in the following ways. First, the task is a more comprehensive and more natural Japanese input task, requiring the input of more characters. In this experiment, the subjects were asked to input a Japanese word or a sentence. Both Japanese words
and sentences consist of several Japanese Kanji. In the real world, Japanese character input in this way is much more frequent and efficient than that used in Experiment 1 which requires the user to input Kanji characters one by one. Second, compared with a single Kanji character, the whole Japanese word which is made up of several Kanji characters, decreases the number of possible candidates and thus shortens the input time and input error rate. Third, we can also investigate whether the number of Japanese characters affects the results of Experiment 1. In the following, we first described the experimental task and whole input process. In light of the experimental results, we present the discussion and implications for input display style design.

3.1. Experimental design

3.1.1. Experimental environment

The experimental environment in Experiment 2 was the same as Experiment 1.

3.1.2. Experimental task

The experimental task was to type a short article or a Japanese word. The paragraph was displayed on the upper part of the experimental system which we developed for the experiment. Instead of inputting Kanji characters separately, the users could input one Japanese word with several corresponding Katakana or Hiragana characters at once in the second step, and convert them to a corresponding word at the same time. In each cycle of the multi-step task, the other steps were the same as those mentioned in Experiment 1.

The total typing time for entering one Japanese word, from the moment a Japanese target word was displayed to the moment the target word was entered, was recorded in 5 segments (t1–t5) as in Experiment 1.

If an incorrect Japanese word was entered, the user was asked to delete the wrong word with the Backspace key or Delete key and then enter the correct word. We defined the number of errors by the number of times the Backspace and Delete keys were pressed.

3.1.3. Display styles

We studied five display styles, all shown in Fig. 8. The Vertical2 is commonly used in Japanese software. In this style the numeric labels of the candidates were laid out in a column, separated from the candidates themselves. In the Compact-Horizontal1 and Compact-Horizontal2, the numeric labels of the candidates were laid out in a row, separated from the candidates themselves. The difference between the display styles was the direction of candidate Japanese words. As shown in Fig. 8c and d, the candidates in Matrix1 and Matrix2 display style were laid in a 3 by 3 Matrix without numeric labels and they could be selected via the corresponding 3 × 3 layout of the numeric keypad in a full keyboard.

In all five display styles the size of each box, candidate character or number, was constant at 0.7 cm by 0.7 cm, the same as for IME-2000.

3.1.4. Selection methods

To select the target characters from many candidates, the subjects were asked to use one of the following seven methods. The first five were the same as in Experiment 1 and have already been introduced in Section 2.1.4. In this experiment, we added two new methods and tried to analyze the results with these.

6. Numeric Keypad method: Selection of a target character was made when a corresponding key on the numeric keypad, either in the top row or at the side of the keyboard, was pressed. This method was used only in Matrix1 and Matrix2 display styles.

7. New Cursor Key method: Designed specifically for this experiment (see Fig. 9), this method was used for Compact-Horizontal1, Compact-Horizontal2 and Vertical2 display styles. In these display styles, selection of a target character was made by pressing the Enter key. This method can be set up in the IME-2000 and ATOK16 which are two commonly used commercial Japanese input methods. Before the formal experiment, all subjects were asked to practice these display styles.
until they were familiar with all display styles. In this method, pressing Page Up and Page Down keys could not trigger the command that scrolls the candidate list page up and down.

The second method (shown in Fig. 9 right) was a new Cursor Key which we designed specifically for this study. Except for Mouse method and Cursor Key method, pressing the Page-Down key with the five remaining selection methods affected a “page turn” within the candidate character display menu. To move back to a previous page, the user simply pressed the Page Up key.

3.1.5. Subjects

Twelve Japanese subjects (9 males and 3 females) participated in the experiment. Their average age was 21.6 years. The subjects had an average of 5 years previous experience in Japanese typing. All had used the Vertical2 display style, and nobody had used any of the other four display styles.

3.1.6. Experimental design and procedure

The experimental task was first explained to the subjects. Before the formal experiment, each subject was asked to practice as much as possible until they were familiar with each display style. They were asked to have a rest between trials during the experiment.

The experiment consisted of typing a paragraph which included 158 characters in total including Kanji, Hiragana or Katakana characters. In the paragraph, the appearance rate of Kanji characters was 45.83. The order of the display styles was randomized. With each style, except the Matrix1 and Matrix2 display styles where the target Kanji characters were selected via the Numeric Keypad alone, each subject began with the unrestricted input method, followed by the four input methods (1–4) in random order. After the traditional selection methods (1–4), the subject was asked to use the New Cursor Key to choose the target. After finishing each session, each subject was asked to rate each display style and the input method used in the session on a 7-point Likert Scale.

The total number of characters typed by each subject was: 5 display styles × 66 practice characters + (3 display styles × 6 input methods + 2 display styles × 1 input method) × 158 actual test characters = 3490 characters.

3.2. Results

3.2.1. Time measures

In the single Kanji character experiment (Experiment 1), we found that there was a significant difference only in “choice reaction time” (t4) between the four styles for each input method. Thus, we report data of “choice reaction time” first. Fig. 10 shows “choice reaction time” (t4) in different input methods and display styles. First, for each of the six selection methods, we examined the differences among the three display styles: Compact-Horizontal1, Compact-Horizontal2, and Vertical2. There was no significant effect for display styles on time taken to choose a target character. We also compared the new Matrix1 and Matrix2 styles with the other three display styles in each of the input methods in “choice reaction time” (t4). The post hoc Tukey HSD test showed that there were no significant display effects between each pair of the five display styles.
Second, for each of the five display styles, we investigated the differences among the six selection methods which were Spacebar, Unrestricted, New Cursor Key, Cursor Key, Numeric Keys and Mouse. When using the Vertical2, there was a significant effect for selection methods on the time taken to choose a target \( (F(5, 66)=3.33, p < 0.05) \). The Spacebar was faster than the other input methods. The post hoc Tukey HSD test showed that the difference between the Spacebar and the Mouse was significant. Furthermore, we compared the Numeric Keypad input method for each of the Matrix1 and Matrix2 display styles with the other six selection methods of Spacebar, Unrestricted, New Cursor Key, Cursor Key, Numeric Keys and Mouse in each of the display styles regarding the time taken to choose the target \( (t) \). When using the Compact-Horizontal1, there was a significant effect for selection methods on “choosing target time” \( (F(7, 88)=2.13, p < 0.05) \); and also when using the Vertical2, there was significant effect for selection methods on “choosing target time” \( (F(7, 88)=2.62, p < 0.05) \). The Spacebar was faster than the other input methods in both Compact-Horizontal1 and Vertical2. The post hoc Tukey HSD test showed that only the difference between the Spacebar and the Mouse selection methods was significant.

### 3.2.2. Error rates

After analysis of Experiment 1, we thought the information of error rate was also important to understand i.e., whether there was a significant effect between different selection methods and error rate or not. Fig. 11 shows the number of errors in the different input methods and display styles.

First, for each of the seven selection methods, we examined the differences among the three display styles of Compact-Horizontal1, Compact-Horizontal2, and Vertical2. When using the Numeric Keys, there was significant effect for display styles on error rate \( (F(2, 33)=4.20, p < 0.05) \). Moreover, the post hoc Tukey HSD test showed that the difference between the Compact-Horizontal1 and the Vertical2 display styles was significant. However, there was no significant effect for display styles on error rate between Vertical2 and Compact-Horizontal2. Next, we compared the new Matrix1 and Matrix2 styles with the other three display styles in each of the input methods. When using the Numeric Keys, there was a significant effect for display styles on error rate \( (F(4, 55)=3.34, p < 0.05) \). The post hoc Tukey HSD test showed that the differences between the Compact-Horizontal1 and Vertical2 each of the Matrix1, the Matrix2 display styles were significant. However, there was no significant difference between Vertical2 and Compact-Horizontal2 display styles. Compact-Horizontal1 had a higher number of errors than the other five display styles (see Fig. 11).

Second, for each of the three display styles, we examined the differences among the six selection methods which were Spacebar, Unrestricted, New Cursor Key, Cursor Key, Numeric Keys and Mouse. When using the Compact-Horizontal1, there was a significant effect for selection methods on error rate \( (F(5, 66)=3.66, p < 0.01) \). The post hoc Tukey HSD test showed that the differences between the Numeric Keys and each of the Spacebar, Mouse, and New Cursor Key input methods were significant. Next, we compared the Numeric Keypad input method for each of Matrix1 and Matrix2 display styles with the other six selection methods which are Spacebar, Unrestricted, New Cursor Key, Cursor Key, Numeric Keys and Mouse in each of the display styles. When using the Compact-Horizontal1, there was a significant effect for selection methods on error rate \( (F(7, 88)=3.25, p < 0.01) \). The post hoc Tukey HSD test showed that the differences between the Numeric Keys and each of the Spacebar, Mouse, New Cursor Key, the Numeric Keypad Matrix1, and the Numeric Keypad Matrix2 were significant.

![Fig. 11. Number of errors.](image-url)
3.2.3. Subjective evaluation

First, for each of the six selection methods, we examined the differences among the three display styles which are Compact-Horizontal1, Compact-Horizontal2, and Vertical2. There was no significant display effect. Next we compared the Matrix1 and Matrix2 styles with the other three display styles in each of the six input methods which are Spacebar, Unrestricted, New Cursor Key, Cursor Key, Numeric Keys and Mouse. The post hoc Tukey HSD test showed that, using the Spacebar the differences between the Compact-Horizontal1 and each of the Matrix1, the Matrix2, between the Vertical2 and the Matrix1, and between the Vertical2 and the Matrix2 display styles were significant. When using the unrestricted input method the differences between the Compact-Horizontal1 and each of the Matrix1, Matrix2, between the Compact-Horizontal2 and each of the Matrix1, Matrix2, between the Vertical2 and each of the Matrix1, Matrix2 display styles were significant.

Second, for each of the three display styles, we compared the new Numeric Keypad Matrix1 and Numeric Keypad Matrix2 method with the other six selection methods which are Spacebar, Unrestricted, New Cursor Key, Cursor Key, Numeric Keys and Mouse. When using the Compact-Horizontal1 or Vertical2, there was a significant effect for selection methods on subjective evaluation \(F(7, 88) = 6.13, p < 0.05\) for Compact-Horizontal1, and \(F(7, 88) = 6.53, p < 0.05\) for Vertical2. The Unrestricted Input Method was better than the other input methods. However, there was no significant difference between the Unrestricted and the New Cursor Key input methods. Moreover, the differences between the Spacebar and each of the Mouse, the Numeric Keys, the Numeric Keypad Matrix1, and the Numeric Keypad Matrix2, and between the Unrestricted and each of the Mouse, Numeric Keys, the Numeric Keypad Matrix1, and the Numeric Keypad Matrix2 input methods were significant. When using the Compact-Horizontal2 display style, there was a significant effect of selection methods on subjective evaluation \(F(7, 88) = 5.07, p < 0.05\). The Unrestricted method was better than the other input methods. However, there was no significant difference between the Unrestricted and the New Cursor Key input methods. Moreover, the differences between the Unrestricted and each of the Mouse, the Numeric Keys, the Numeric Keypad Matrix1, and the Numeric Keypad Matrix2 input methods were significant. And d) do not agree with the results for the Matrix (Fig. 3d) display styles in Experiment 1. The reason may be that when displaying more than two characters rather than single characters, Matrix1 and Matrix2 are not square-shaped so that they are not as good for searching for the target candidate. Unlike Compact-Horizontal1, Compact-Horizontal2 and Vertical2 require only one line eye movement for recognizing nine candidates. Matrix1 and Matrix2 require more eye movements. However, if we create a display style candidate with numeric labels which correspond to the \(3 \times 3\) keys layout in the Numeric Keypad, we may provide an intuitive interface which novice users will easily understand.

Regarding the Compact-Horizontal2 and Vertical2 styles, all subjects had used the Vertical display style of Japanese input software as shown in Fig. 1b and c for an average of five years. However, no subject had used the other display styles before the experiment. Moreover, there was no significant difference in either performance or subjective ratings between the two styles. Therefore, Compact-Horizontal2 display styles can be regarded as a good design choice.

Not surprisingly the Unrestricted and the Spacebar methods were superior to other methods because they include all other input methods and all subjects use the spacebar every day. We designed the new Cursor Key for solve the problem experienced when using the traditional Cursor Key, i.e., the user has to extend the finger from the home position to the Page Up or Down keys. Mistakes made by this operation are common, particularly for novice users. To solve the problem, we designed the left, right, up and down cursor key to do Page Up or Page Down operations for the Compact-Horizontal1 and Compact-Horizontal2 styles. This means that the New Cursor Key includes the Traditional Cursor Key and Page Up or Page Down functions.

In the subjective evaluation, the New Cursor Key was also rated more highly than the Traditional Cursor Key when using both Compact-Horizontal1 and Compact-Horizontal2 styles. Furthermore, two participants preferred the New Cursor Key over the Traditional Cursor Key because “it will be easy to use when we get used to it, and the New Cursor Key was able to be used naturally”. Moreover, based on subjective preferences, when using Compact-Horizontal1 and Vertical2 display styles, the seven input methods can also be classified into the three groups: (1) Unrestricted, Spacebar, (2) New Cursor Key, Cursor Key, (3) Numeric Keypad (i.e., Matrix1 and Matrix2), Numeric Keys, Mouse. When using Compact-Horizontal2 display styles, the seven input methods can also be classified into the three groups: (1) Unrestricted, (2) Spacebar, New Cursor Key, Cursor Key, (3) Numeric Keypad (i.e., Matrix1 and Matrix2), Numeric Keys, Mouse. It is noteworthy that, the New Cursor key is in the same position with the Spacebar, which indicates that the New Cursor Key is a good design choice, in particular, for the Compact-Horizontal2 display style.

3.3. Discussion

In our single Kanji character experiment, Compact-Horizontal (Fig. 2a) and Matrix (Fig. 2c) were superior to other display styles in performance and in the subjective evaluations. The result for Compact-Horizontal2 (Fig. 8b) is the same as for the single Kanji character experiment. However, the results for the Matrix1 and Matrix2 (Fig. 8c and d)
4. Experiment 3: Single Chinese character input

Japanese Kanji characters originated from the Chinese language. Users input Chinese through the *pinyin* input system as an intermediary while they input Japanese through the *romaji* input system. Both Experiment 1 and Experiment 2 investigated the Japanese input method. In Experiment 3, we investigated whether the different languages affect the relationship between display styles and input time, and we also studied the difference and similarity between Japanese input and Chinese input.

4.1. Experimental design

4.1.1. Experimental environment

The differences between the experimental environment in Japanese and the one in Chinese are as follows: Firstly, a common English 101 Keyboard was used in this experiment. The key layouts of Japanese and English styles are different, especially for the symbol keys. Secondly, we used IME2003 and MS-Pinyin98 as Chinese conversion software in our experimental system.

4.1.2. Experimental task

The experimental task used in the study was single Chinese character input. The experimental setup was similar to the one in the single Japanese character input experiment. In each cycle of the multi-step task, a Chinese character and its pinyin character were first displayed on the screen. Second, the subject input pinyin by typing its corresponding Roman letters via the keyboard. Third, the pinyin was converted to a Chinese character by pressing the spacebar. If the resulting Chinese character was not the intended character the subject pressed the spacebar once again, and a list of candidates was displayed. Fourth, if the intended character was not in the list, the subject visually scanned and located the intended character by repeatedly pressing the page down key, the space bar or the cursor key, or by mouse clicking on the scrollbar on the display style to bring up the next set of candidates, until the intended character was found. Finally, the subject selected the target Chinese character by pressing the enter key, the numeric Keys, the mouse button, space bar, numeric key pad or unrestricted.

4.1.3. Display styles

The display styles shown in Fig. 12 in this experiment are same to those in the single Japanese character input experiment.

4.1.4. Selection methods

Selection methods are similar to those for a set of Japanese characters input.

4.1.5. Subjects

Twelve Chinese subjects (5 males and 7 female) participated in the experiment. Their average age was 30.25 years.

![Fig. 12. Four candidate display styles for single Chinese character input. (a) Horizontal display style for Chinese input, (b) Compact Horizontal display style for Chinese input, (c) Vertical display style for Chinese input and (d) Matrix display style for Chinese input.](image)

Subjects had an average of 5.45 years previous experience in Chinese typing. 11 subjects had used the Horizontal display style for 1.3 years, and 6 subjects had used the Vertical display style for 1 year.

4.1.6. Experiment design and procedure

The experimental task was first explained to the subjects. Each subject was given ten practice trials with each input method and display style. They were asked to have a rest between trials.

Tests consisted of typing 20 Chinese characters with each display style and input method. The order of the display styles was randomized. With each style, except the Matrix style where the target Chinese character was selected via the Numeric Keypad alone, the subjects began with the Unrestricted Input method, followed by the 4 remaining input methods in random order.

These 20 Chinese characters took 952 Roman letters to specify. The number of page up/down operations needed in typing a character depended on the number of candidates displayed per page.

4.2. Results

4.2.1. Time measures

The total typing time, from a target character being displayed to the target character being selected, was recorded
as 5 segments, which were the same as in Experiments 1 and 2:

Based on the single Kanji character experiment, “choice reaction time” is mainly discussed here. From the experiment results (shown in Fig. 13), the display effect did not affect the choice time using all of the selection methods and the Compact-Horizontal was the fastest one among all display styles.

4.2.2. Error rates

For each of the three display styles, we compare the error rates with the six selection methods which are Unrestricted, Cursor Key, Spacebar, Mouse, Numeric Keys, and Numeric Keypad (shown in Fig. 14). When using the Mouse, there was a significant effect for display styles on error rate ($F(2, 33) = 5.48, p < 0.01$). When using the Numeric Keys, there was a significant effect for display styles on error rate ($F(2, 33) = 4.26, p < 0.05$). For the other selection methods, there was no significant effect.

4.2.3. Subjective evaluation

Fig. 15 showed us that Compact-Horizontal was the most popular display style when using the Cursor Key and the Spacebar. More subjects preferred the Vertical display style when using the Mouse. Just as in Experiment 1, most of the subjects preferred the Matrix display style and they mentioned that corresponding visual feedback assisted character input.

4.3. Discussion

This section discusses the relationship between display styles for candidate lists and single Chinese character input. From the experiment results and subjective evaluation, Compact-Horizontal style was the fastest style for choosing a character when using the six selection methods excluding the Numeric Keys. If the subject used Numeric Keys, the Matrix style was preferred. The phenomenon is the same as in the single Japanese characters input experiment.

5. Conclusion and discussion

This study contributes to our understanding of both Japanese and Chinese text input. We investigated the relationship between different display styles and character input styles in Japanese and Chinese. We designed three experiments: single Japanese and single Chinese character input and inputting a set of Japanese characters, to investigate this relationship. The effects of different languages and different numbers of characters were considered here. Typing time was measured in the single Japanese character input experiment. In the first experiment, we
used typing time to study the error rate for choosing characters. Moreover, the error rate was added to investigate the user’s action when we designed the second and third experiments.

In the first experiment we found that, as in Chinese input (Wang et al., 2001), choice reaction and selection (t4) in Japanese input takes a great deal of time. During single Japanese Character input, the results showed that Compact-Horizontal and Vertical were overall more efficient than the Horizontal display style. It can be said that the Compact-Horizontal display style is a good design choice.

In the second experiment, we conducted an experiment inputting Japanese characters to test five the display styles which are Vertical2, Compact-Horizontal1, Compact-Horizontal2, Matrix1, and Matrix2 styles, together with the seven selection methods which include Spacebar, Unrestricted, New Cursor Key, Cursor Key, Numeric Keys, Numeric Keypad, and Mouse. The results showed that the conversion candidate display styles of Japanese input affect input efficiency in terms of performance and subjective evaluation. We found that the Compact-Horizontal2 and Vertical2 display styles are better than the other display styles but no significant difference between the two styles was apparent. It can also be said that the Compact-Horizontal2 display style is a good design choice because no significant difference was observed between the Compact-Horizontal2 and Vertical2 styles even though the subjects had used the Vertical2 style for a long time.

It was clear that the Spacebar, the new Cursor Key, and the Cursor Key were suitable for the Compact-Horizontal2 style. The new Cursor Key was superior to the traditional Cursor Key based on subjective ratings, input efficiency, and the subjects’ comments. The results of our single Kanji character experiment showed the Compact-Horizontal and Matrix display styles were superior to the other display styles including the Vertical style. Taking the results of the two experiments together, the Compact-Horizontal2 style could be regarded as the best of these display styles.

In the third experiment, the conclusion, which was the same as for single Japanese character input, can be summarized. The results of this study may also apply to text input in other non-alphabetic languages, and perhaps to multiple choice selection tasks beyond text input.

In summary, choice reaction and selection in both Chinese and Japanese input takes a great deal of time in the process of character input. The conclusions were the same with both Kanji characters in Japanese and Chinese and for different numbers of characters. The results of the three experiments all show that the Compact-Horizontal display style outperformed other display styles but the Matrix display style was the best to use when using numbered candidate displays.

The results of our experiments are promising for three reasons: one reason is that we present S-R compatible solutions. The sequence of numbers from one to nine (Fitts and Seeger, 1953) was convenient for users to choose the characters in Compact Horizontal display style. The second reason is that both Japanese and Chinese users have the same culture i.e., they write and read the characters. They are all familiar with scanning patterns from left to right, and top to down on computers. If people are used to inputting characters vertically, maybe they prefer the vertical display style as it is a habit. Another reason is within category recognition. The horizontal display style mixes the number and character candidate and it disturbs the continuity of recognition; by contrast, in the Compact Horizontal display style the character candidates are separated from the numbers and users can find the right character without disturbance.

In this study, we set up 9 as the number of choices by Numeric Keypad input method. However, we may extend the result to a different number of choices (either smaller or greater than 9). It is based on Hick’s law \( T=b \log_2(n+1) \) which is well known and used to estimate the time of multiple-choice reaction. “n” stands for the number of candidates. With the increase or decrease of “n”, the choice reaction time the target increases or decreases with all input methods together. It may not change the final result among these input methods.

Finally, some research questions remain. In this study, the order of the candidate characters tested is the same for
all the subjects. This is to keep the same experimental conditions for the subjects. In current commercial Chinese or Japanese character input applications some intelligent input methods are used to input characters or sentences so that the order or the length of candidate characters may be different even though for same user. Furthermore, more space is inserted between each character and number label pairs may affect the experiment results. These questions will be explored in the future work. This study employed participants who were all university students with a lot of experience inputting such characters. Future work will investigate the differences between old people, young people and children. We will also look at whether our results are suitable for text entry interface design on mobile phones or not.

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