Int. J. Human-Computer Studies (2002) **57,** 447–468
doi:10.1006/ijhc.2002.1027
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Visual search strategies and eye movements when searching Chinese character screens

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(Received 31 January 2002 and accepted in revised form 26 August 2002)

Most visual search studies have been restricted to alphanumeric stimulus materials. Research related to scanning patterns of Chinese characters is sparse. This study is an attempt to understand the differences and similarities in visual search of Chinese characters having a varying degree of complexity among Hong Kong Chinese, Mainland Chinese and Chinese reading non-Chinese people. Eighteen participants were tested on Chinese character screens with three layouts (row, column, and uniform separation) and two word complexities (high and low). The 18 participants comprised six Hong Kong Chinese, six Mainland Chinese and six non-native Chinese readers. Performance data and eye movement data were recorded. The percent correct and search time were the two performance measures. A new measure, called HV-ratio was developed to characterize eye movements. The results show that Hong Kong Chinese use predominantly horizontal search patterns while the Mainland Chinese change their search pattern depending on the layout presented. Non-native Chinese readers, on the other hand, do not seem to show any preference on scanning strategy for a given layout. Word complexity did not show any significant effect on search time. Potential reasons for these differences and design implications are discussed.

KEYWORDS: eye movement; visual search; Chinese; reading pattern; character search; word complexity.

1. Introduction

The literature related to visual search performance and search strategies of Chinese is sparse. This study is an attempt to understand the differences and similarities in visual search of Chinese characters having a varying degree of complexity among Hong Kong Chinese, Mainland Chinese and Chinese-reading non-Chinese people.

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1.1. CHINESE CHARACTERS

Chinese characters are square and rectangular (Tang, Au Yeung & Chen, 1997). Unlike alphanumeric transcription of words in for example English, Chinese characters can present difficulties to those who are not familiar with it due to the many variations and formats (Seymour, 1989). Today, about 3000–4000 characters are used in most publications. Many different types of identification processes exist for Chinese characters. The radical system invented in the 18th century is the first. Radicals are the ''elements'' of all Chinese characters. Approximately, 80% of them are characters, but are generally used in combination with others. In the Kangxi dictionary, 214 radicals were identified and listed by stroke count. As Hoosain (1991) pointed out, ''radicals can occur in different locations in the square space of resultant characters, although many radicals have habitual locations''. (p. 10). In the 20th century, other systems such as the 4-corner (Wong, 1926), stroke encoding (Li & Li, 1985), sequence and division methods have been used. The traditional radical system learnt by many in a formal way is not as simple as it may appear. Familiarity with traditional stroke counting is necessary to identify the radicals in a complex Chinese character. Chinese dictionaries published in Japan reversed the radical method: the primary divisions were based on the number of strokes and the subdivisions based on radicals. This raises an important question in relation to recognition: do character strokes help recognize Chinese characters easier than radicals? With a total of approximately 36 stroke counts (a few characters have more than this number), there were almost 1000 characters under most strokes. The radical system is too difficult, if not impossible to use for anyone not proficient with Chinese. It would be necessary to have a ''system of identification which allows a person to find a character rapidly without detailed knowledge about the Chinese writing system. Both radical and stroke count systems require knowledge of traditional conventions''. (McCawley, 1984, p. 9). ''Over the years, more than 100 systems have been proposed for overcoming the difficulties (of the radical system)'' (Kwei, 1979, p. 3) in an effort to identify Chinese characters. Around the mid-20th century, the Chinese government recognized the difficulty for the Chinese population to learn so many complex characters. As a result, in 1956, the Chinese government released a list of simplified characters. ''The number of characters in use was reduced, as well as the number of strokes in many individual characters.'' (DeFrancis, 1984, p 260). This simplified form is now used in Mainland China and the complex (traditional) form is used in Hong Kong and Taiwan (China, 2002). An example of the two forms for the word ''festival'' follows: 節 in traditional script and 节 in simplified form.

1.2. WORD COMPLEXITY

The complexity of the words is characterized with the use of the number of strokes, which varies from 1 to 37 (Figure 1). As an example, there are around 220 words with five strokes, around 1100 words with 10 strokes, and around 1600 words with 15 strokes and so on (Xin ci dian, 1989). Cheng (1982), through a survey of over a million characters, reported that the average number of strokes of the 14 most frequently occurring traditional script characters is 6.5. Chan (1982) reported that the average is 5.6 for the 14 most frequently occurring characters in simplified script. Similarly, the

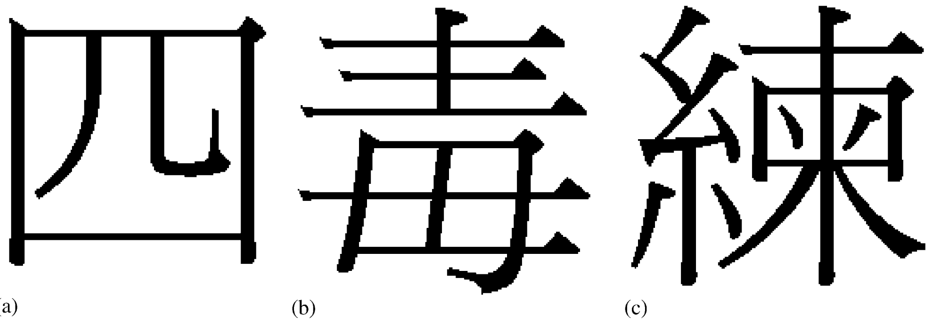


FIGURE 1. (a) 5-stroke character (four) (b) 10-stroke character (poison) (c) 15-stroke character (practice).

average number of strokes reduced from 11.2 (traditional) to nine (simplified) for the 2000 commonly used characters.

The information content of each character tends to be different in the four quadrants of a character as characters are written left to right and top down. Peng (1982) analysed the cognitive complexity of 3000 characters and found that the top-left quadrant had more complex sub-patterns and more junctions of component strokes than the bottom-right quadrant.

The component strokes of characters are usually written left to right as well as top down. In traditional script, characters are written in vertical columns top down and columns proceed from right to left. With the establishment of the People's Republic of China and the introduction of simplified Chinese subsequently, characters are now written horizontally and proceed from left to right. Even though the visual field has a greater horizontal extent than the vertical region, the foveal vision that allows us to identify critical detail tends to be more circular (Hoosain, 1991; Woodworth & Schlosberg, 1954). Thus, the square-shaped Chinese characters may be easily searched relative to the more elongated English words. Freeman (1980) found that random English letters were better seen when in horizontal rows rather than vertical columns. However, Freeman (1980) also reported that there was no such horizontal and vertical orientation acuity difference for native Chinese when presented with Chinese characters. Freeman attributed the differences to a language experience rather than national origin as Chinese tends to be written both horizontally and vertically unlike English and thereby no acuity difference seems to exist in relation to orientation. Generally, people prefer to scan visual materials from left to right or from top to bottom (e.g., Aaron & Handley, 1975). Younger readers of Hebrew (which is written from right to left) show a scanning preference of right to left even with non-Hebrew materials. But, this tendency is reversed with mature Hebrew readers (Braine, 1968; Kugelmass & Lieblich, 1970). Thus, it appears that even though there may be a preference towards a certain direction of visual scanning, language experiences may modify any such norms.

1.3. ORIENTATION EFFECTS

Research shows that reading direction does affect visual parameters. For example, the English language reader has an effective visual field or perceptual span that is asymmetric, extending about four characters to the left of the letter being fixated and about 15 characters to the right (Rayner, Inhoff, Morrison, Slowiaczek & Bertera 1981). Pollatsek, Bolozky, Well and Rayner (1981) has shown language dependencies in relation to this asymmetry. A search field that fits the visual lobe efficiently is known to facilitate visual search performance. Hence, this presents us with an important parameter that needs investigation in relation to the visual search process of Chinese users. In the English language, words are different in length, in height and in form (Tang *et al.*, 1997). However, there is no increase in size of Chinese characters with increases in the number of strokes. Chinese characters, unlike English, have very high construction complexity and are equally spaced with each character having a similar square box-like shape (Tang *et al.,* 1997). Every Chinese character is a word that has its own meaning and unique appearance. Due to the rectangular (or square) shape of Chinese characters, the character itself does not provide any cue for the reading orientation. As mentioned before, since Chinese characters have more information in the top-left quadrant, and if attention is focused on the more informative parts first, then one may expect the preferred scanning direction when reading to be left to right and/or top down unless one prefers "back-tracking". Chen and Chen (1988) showed that the language experience of young children governs the preferred scanning direction. With advanced readers, however (similar to the difference between young Hebrew readers and mature Hebrew readers), it is not clear whether the scanning patterns are reversed.

Performance differences can be used to assess the "efficiency" of visual search (Wolfe, 2000). Layout or orientation has an important impact on the ease of use of computer-based systems (Backs, Walrath & Hancock, 1987). Previous studies on visual search performance, when information is arranged in rows and columns, are contradictory. For example, Coffey (1961), using one row/column and three rows/columns, showed that there is no difference in visual search performance between the horizontal (row) and vertical (column) arrangements of *alphabetic* materials. Williams (1966) evaluated vertical and horizontal arrangements of *three-digit numbers* and showed that the horizontal arrangement of the three-digit numbers yielded superior performance. Due to the nature of the task, it was necessary for the participant to have vertical eye movements to go from symbol to symbol within a column and then horizontal eye movements for comparisons between columns. Woodward (1972) hypothesized that the contradiction between the Coffey (1961) and Williams' (1966) studies were due to the differences in structure of the search field (physical size of the stimulus material) and the task complexity. He also suggested that Williams' results might be due to the proximity of the individual digits that were compared rather than the horizontal/vertical layout difference. Woodward (1972) tested distal/proximal, row/column, and horizontal/vertical factors using a pairwise digit comparison of three-digit numbers similar to that of Williams (1966). The task was to compare many three-digit number pairs in a search field and identify the pair that was different. In the distal arrangement, the number pairs were arranged end to end (e.g. 123 123) and in the proximal arrangement, number pairs were arranged "side by side" (e.g. $\begin{matrix}123\\123\end{matrix}$). The distal/proximal factor was used for varying the format of the search field, and to classify the format in a precise way. Participants in Woodward's (1972) experiment were recommended appropriate scanning patterns in each arrangement, i.e. horizontal eye movement were proposed for the horizontal arrangement and vertical eye movement for the vertical arrangement. He showed that participants had significantly better performance when each of the three-digit numbers were arranged in horizontal direction. But, the row and column arrangement (i.e. direction in which the participant moves from a group of pairs to the next) of the number did not show any significant difference. That study also found the proximal arrangement had lower search time than distal arrangement. The reason stated was that, if the pair of three digit numbers is arranged in proximal format, the two numbers are located within a 5-degree visual lobe and hence only one fixation was required to distinguish any difference between digits of the two numbers. When the numbers were arranged in distal format, two fixations were required to examine each pair of numbers. In other words, the spacing between stimulus material has an effect on search performance. In all three studies, the eye scan patterns can take a complex form as there is a general direction of movement as well as a comparison which takes place in a different direction. The complex interaction between task complexity and eye movement may have contributed to the performance difference.

Other studies have shown that the vertical (column) format results in improved search performance. Backs *et al.* (1987) investigated the orientation effects of horizontal/vertical full screen menus on search time. They used menus with 4, 8 and 12 items in both horizontal and vertical orientfations and showed that vertical menus lead to improved performance. Participants in that experiment also commented that the vertical orientation was easier to use. The horizontal menus in their experiment had four items in *each* row and thus the external validity of the result when more items are present is suspect. Parkinson, Sisson and Snowberry (1985) also suggested that vertical alphabetic menus (i.e. in column format) lead to improved performance. However, the spacing between columns was larger than the spacing between rows and hence the result may be biased (Emurian & Seborg, 1990).

Researchers have shown that there are substantial effects of visual target eccentricity on reaction time. For example, the Yund group (Efron & Yund, 1966; Yund, Efron & Nicolas, 1990; Yund, 1996) have found right field superiority. Others such as He, Cavanagh and Intriligator (1996) have shown lower field superiority and upper field superiority has been shown by Previc (1996), Previc and Blume (1993).

Due to these confounding effects, the conclusion that a "vertical layout is efficient", may be unique to the stimulus material (mostly alphanumeric) used, layout parameters and the Western participants.

1.4. THE CULTURE FACTOR

With globalization, designing for universal access has received much attention in the recent past (Fernandes, 1995; Stephanidis, 2001) as the language experience can affect the design guidelines such as those proposed by Mayhew (1992). The differing scanning patterns of people, based on their language experiences, can have an effect on visual search performance (Nielsen, 1990). Since the Chinese language has two predominant orientations (a horizontal or "Z" type orientation, starting in the top left corner of the paper and a vertical or inverted "N" type orientation, with text starting in the top right corner of the page) (Figure 2), the search patterns of Chinese users may have interesting

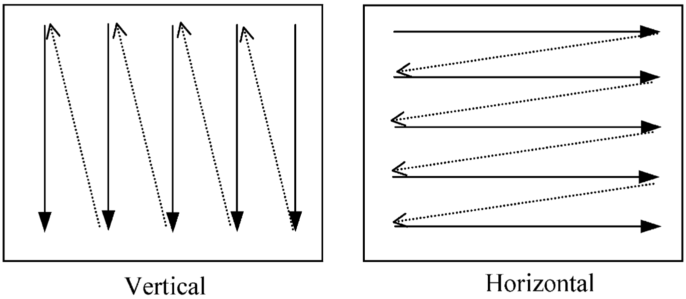


FIGURE 2. The common reading patterns of Chinese.

design implications for "full" screen information presentations. Shih and Goonetilleke (1998) studied the effect of layout with Chinese words having Hong Kong Chinese as participants. Their results showed that Hong Kong Chinese participants search faster in one-row word menus when compared to one-column menus. They attributed their finding to a writing style difference (that is, traditional Chinese script adopted in Hong Kong is written top down from right to left) and suggested a "matrix transposition" to break the flow when displaying menu items written in Chinese. That study was limited to a tool-bar type of menu and the external validity of those results to a full-screen menu has great importance in an age where web-based screens are ubiquitous. Sengupta and Liu (1999) on the other hand, have argued that information layout in process control screens for Mainland Chinese can follow a format similar to those of Westerners as the "Z" pattern is dominant in Mainland China. In their paper, they also stated potential differences between Hong Kong groups and Mainland Chinese groups. A third potential group relates to non-native Chinese readers who may be used to languages such as English. Thus, it is important to identify potential differences amongst these groups that read Chinese.

1.5. STUDY RATIONALE

It is clear that stimulus material, layout parameters, and the participants have distinct effects on visual search performance. Due to the tremendous number of variations for each variable, it is appropriate to concentrate on variables that can potentially have design implications. Generally, reaction time or accuracy is evaluated as a function of "set size" (that is, the number of items in a display). Several previous studies have shown that search field complexity has a significant effect on search duration (Coffey, 1961; Drury & Clement, 1978; Chen, Healy & Bourne, 1985; Muller & Found, 1996; Hogeboom & Leeuwen, 1997); more menu items results in an increase of search time. Complexity of targets and non-targets has been found to affect the detectability of a target (Scharroo, Stalmeier & Boselie, 1994). Since Chinese characters can have varying complexities (number of strokes in each character), it is important to account for any potential interactions and confounding effects as a result. It appears that people tend to use a reading scan pattern in general. However, in a search task, a matrix transposition may help search the required item, as a break of words will quicken the search process

(Shih & Goonetilleke, 1998). Based on the aforementioned literature, we hypothesized that the cultural difference could possibly interact with different types of layouts and have an impact on search performance and search pattern.

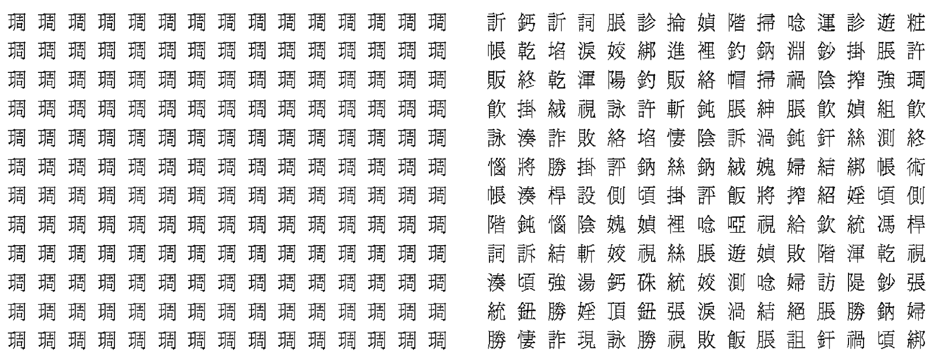
Thus, the hypotheses investigated were as follows:

- Population group, word complexity and layout and their interactions have a significant effect on search performance.
- There are significant main effects and interactions among the above variables with respect to search strategy.

2. Methods

2.1. EXPERIMENT

A standard visual search experiment (Wolfe, 2000), where a participant was looking for one target item in a display with a number of distractors was used. The objective of the task was to find a Chinese word (target word) in a full screen search field. First, the target word was shown to the participant on a "Target screen" [Figure 3(a)]. In the "Target screen", all the words were the same target word [for example, 琱 as shown in Figure 3(a)]. Human eyes have a tendency to move to the centre of gravity of a display (Findlay, 1995; Zelinsky, Rao, Hayhoe & Ballard, 1996) and if the target word was just one word on the whole screen, it can introduce an eccentricity artefact resulting in possible confounding. The reason for filling the screen with the target word was to prevent any starting position bias when the target word screen changed to the next screen. After the participant "recognized" the word, he/she would hit a button signalling that he/she was ready to proceed with the actual search and the "Search screen" was then shown [Figure 3(b)]. The search screen had the target word among many other words. Cheng (1981) found that Chinese characters are perceived well when embedded in a word context rather than in a non-word context. To avoid any biases as a result, each character (word) on the search screen did not form any meaningful context. The target screen had the same layout as the search screen.



(a) (b)

FIGURE 3. (a) Target screen of experiment. (b) Search screen of experiment.

2.2. EXPERIMENTAL TASK

The participant was requested to search for the target word in the search screen as fast as possible. In each of the search tasks, the participant had 90 s to find the target word. If the participant was unable to find the target word within 90 s, the next trial was presented to the participant automatically. If the participant thought that the search field did not contain the target word, he/she would press the "Give up" button to terminate the trial. The experimental time ranged from 1 h 20 min to 1 h 50 min.

2.3. EXPERIMENTAL DESIGN

The experiment was a 3 (Population) $\times$ 3 (Layout) $\times$ 2 (Word-complexity) $\times$ 10 (Trial) design. Each participant completed three practice trials and a total of 60 experiment trials (10 trials each for the 3 Layouts and 2 Word-complexities). The independent variables–Layout (3 levels) and Word-complexity (2 levels) composed six experimental conditions. The trials were "blocked" by these six experiment conditions and each block consisted of 10 trials. The testing order was balanced among participants by using the six conditions to form a Latin square-like arrangement.

The experimental variables were as follows.

(1) Three Population groups that read Chinese: Hong Kong Chinese, Mainland Chinese and non-native Chinese

(2) Three different Layouts: row, column and uniform separation

(3) Two different Word-complexities: high and low

The three layouts were constructed by varying the separation between rows and columns. The "Row" (R) layout (Figure 4) was similar to the horizontal (Figure 2)

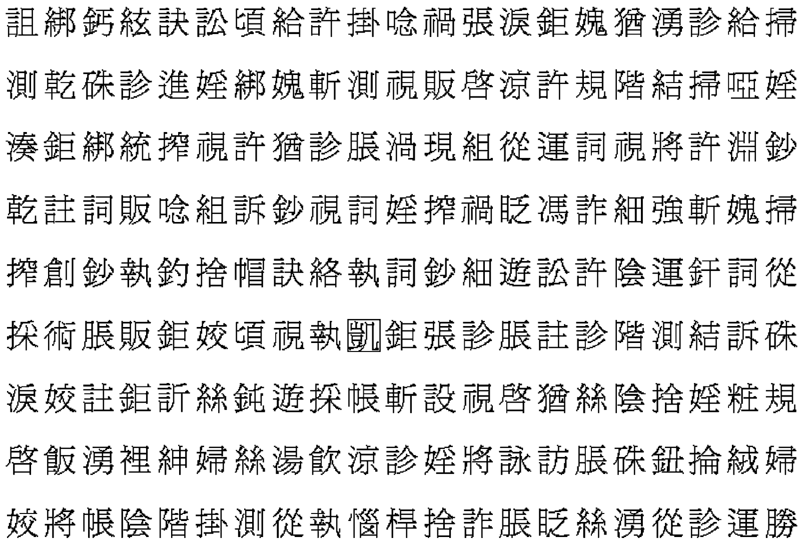


FIGURE 4. An example of a Row layout.

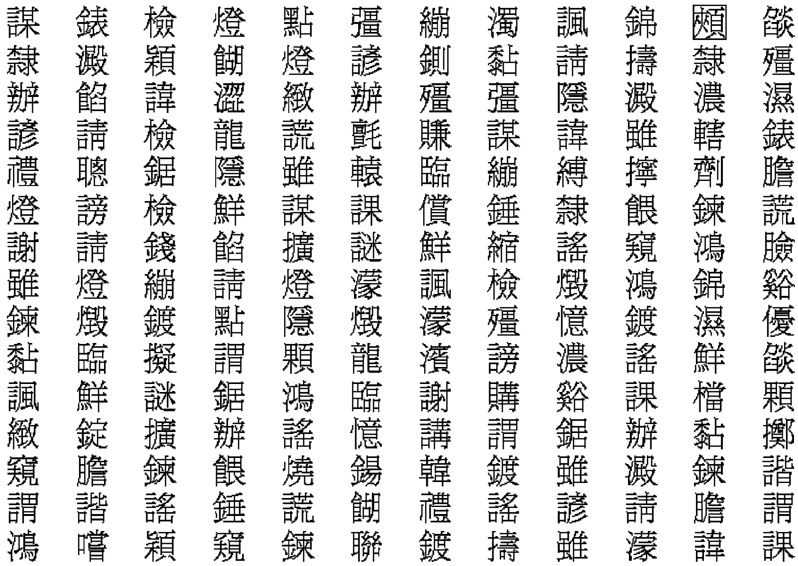


FIGURE 5. An example of a Column layout.

writing format ("Z" type) of Chinese text. There were nine rows and 21 columns (corresponding to a height of 16.1 cm and width of 22.5 cm) of words (that is a total of 189 words). The average space between columns was 0.2 cm and that between rows was 1 cm.

The "Column" (C) layout (Figure 5) was similar to that of the vertical (Figure 2) writing format ("N" type). There were 15 rows and 12 columns (i.e. 180 words) equivalent to a dimension of 22.5 cm width and 16 cm height. The size of each word was the same as in Row layout. The average space between columns was 1.06 cm and that between rows was 0.18 cm.

The third layout was called "Uniform" (U) separation (Figure 6) where the row and column separations between words were perceived to be the same. In this layout, there were 12 rows and 15 columns (i.e. 180 words) with a dimension of 22 cm width*16.3 cm height. The mean spacing between columns was 0.55 cm and that between rows was 0.5 cm.

The density of the search items can affect the search performance (Emurian & Seborg, 1990). In addition, Scott and Findlay (1993) have found that the shape of search field also affects the search duration and saccadic distance. In order to eliminate any bias as a result of these two factors, the area and shape of the search field were controlled as much as possible. The differences in the physical size of the search field in the three different layouts were very small (that is a maximum of 3 mm between the uniform layout and the column layout) and this difference was not perceivable. Hence, the area and shape should not have any confounding effect with the independent variables.

In order to balance the positions of the target words among all the trials and the three layouts, the search area was divided into nine equal areas (these areas have been

FIGURE 6. An example of a Uniform layout. Superimposed on it are the nine target areas.

superimposed in Figure 6). The distance from the participant's eyes to the computer monitor was approximately 50 cm. Hence, the projection of a 5 degree visual lobe (Woodward, 1972) was around 4.4 cm. Thus, the length of each target area was equivalent to around 1.7 times the visual lobe size without any overlapping. Nine of the 10 trials of each experimental condition contained one target in the search field; the other trial did not. The target in each of the nine trials was randomized among one of the nine areas with the target being present only once in one area over the nine trials. The exact position of the target word within an area was also randomized.

Even though the set size of the three different layouts should be the same, it was impossible to keep the number of items in the three layouts exactly the same while keeping the search area and shape constant among the three layouts. The separation between items in Row and Column layouts also had to be kept approximately in the same proportion. To minimize any artefacts, the differences were kept to a minimum. In the "Row" layout, the number of words in the search field was 189, while there were 180 words in both "Uniform separation" and "Column" layouts. The set size difference was thus 4.7% and was assumed to be negligible.

The Chinese words used in the experiment were selected based on their word complexity. Two word complexities (High and Low) were used in this experiment. "Low complexity" words were those that had 10–12 strokes. "High complexity" words were those that had 16–18 strokes. Only Chinese words with a left–right format (for example 講 for "Talk") were selected. Those Chinese words with a top-down format (for example 葉 for "leaf") were not selected, as Chinese words with a left–right format are generally much clearer on a computer display. The size of the Chinese words were

$9\,mm \times 9\,mm$, equivalent to a visual angle of 1°. The target word was randomly chosen from a list of 36 different words. The words on the search screen were randomly selected from a list of 100 different words. Each of these words appeared 1 or 2 times in each screen.

2.4. PARTICIPANTS

A total of 18 paid participants [six Hong Kong Chinese (H), six Mainland Chinese (M), and six non-native Chinese readers (F)] were tested. The objective of the study was to understand the similarities and differences among these three groups when searching Chinese characters. Considering the lengthy process involved with eye-tracking systems, only six participants were used in each group. The age range of the participants was 13–36 years. All participants recognized the Chinese words used in the experiments. The Hong Kong Chinese participants (age range 22–24 years) were university students and had Cantonese as their first language. The Mainland Chinese group (age range 23–26 years) were also university students but were present in Hong Kong for less than 1 year. The non-native Chinese readers were those who had experience with the Chinese language but whose first language was not Chinese. They were chosen so that they all recognized the Chinese words that were used in the experiment. This group had an age range of 13–36 years and the participants' occupation varied from a secondary school student to a university lecturer.

Each participant received a "base" payment of HK$ 20. For each correct search and each correct "give-up", the participant received HK$ 1 and for each incorrect search HK$ 1 was subtracted.

2.5. MATERIALS AND EQUIPMENT

The experiment was programmed using Visual Basic 6.0 and was run on a Pentium computer in the Microsoft Chinese Windows 98 environment. The participant responses were acquired using a touch-screen monitor. A photo sensor was used to determine the time at which the preferred hand left a fixed location to make a response on the touch screen. These signals were used to determine search time and response accuracy. The Applied Science Laboratories (ASL) 5000 eye tracking system with the Flock of Birds head tracker (Applied Science Laboratories, 2002) was used to record the participant's eye movement during the search task. In this system, the eye is illuminated by a near-infrared source and the optical system focuses the eye image into an "eye-camera". The eye-camera "tracks" the location of the beam on the eye and the corneal reflex. The control unit of the system processes the eye-camera signal to give the pupil diameter and the line of gaze. A video scan converter was used to convert the computer display output to a video signal for recording the eye movement data. In addition to the experimental computer, a hardware panel (with the give-up and continue push buttons) and a controlling computer were present. Additional equipment, such as video cameras, Vision Tester, and digital flicker meter were used to check the participant visual acuity, visual fatigue, and posture during experiment.

2.6. PROCEDURE

Prior to the actual experiment, each participant was given three practice trials. The eye tracking system was calibrated and positioned on the participant's head. Then, each participant completed the 60 experimental trials. In all trials, the target word screen was shown first. After the participants recognized the target word, they were asked to press the external "Continue" button to proceed to the search screen. When the search screen was shown, the participant had to find the target word as fast as possible. Once the participants found the target word, they were asked to "touch" that word on the touch screen monitor. If they were unable to find the target word or thought that the word did not exist on the screen, they were asked to press the external "Give-up" button to end the trial. If the participant was unable to find the target word within 90 s, the next trial was presented to the participant automatically.

3. Results and analysis

3.1. PERFORMANCE ANALYSIS

Performance and eye movement data were analysed. The two performance measures were search time and accuracy (or % correct). Percent correct represented the percentage of trials having "Hits" or "Correct Rejections" within each experimental condition. These represent the trials in which the target word was found or where the participant correctly gave up a search as the target was not present in the search field.

The three-way (Population x Layout x Word complexity) ANOVA on Percent correct showed a significant effect for Population [$F\,(2, 90) = 10.49$, $p < 0.0014$]. The *post hoc* analysis showed that non-native Chinese (mean = 81.2%, S.D. = 12.39) had significantly lower percentage correct than both Mainland Chinese (mean = 91.7%, S.D. = 8.12) and Hong Kong Chinese (mean = 96%, S.D. = 7.58). There was no significant difference between Mainland Chinese and Hong Kong Chinese. In addition, Layout [$F\,(2,90) = 0.21$, $p < 0.81$], Word Complexity [$F\,(1, 90) = 0$, $p < 0.94$] and all other interactions were not significant at the $p < 0.05$ level for the dependent variable, percent correct.

3.2. SEARCH TIME ANALYSIS

The time to locate the target correctly in each trial is search time. Unlike the accuracy measure, the starting position and search strategy can have a significant effect on search time. Hence, target position was considered as an added "variable" in order to determine search strategy. Since the search time data was not normal, Square Root Search Time (SRST) was used, based on a Q–Q plot normality test (Johnson & Wichern, 1992). The four-way Population * Layout * Word complexity * Target position ANOVA for SRST showed that Population [$F\,(2, 709) = 24.6$, $p < 0.0001$], Target position [$F\,(8, 709) = 5.5$, $p < 0.0001$], and the Target position * Population group interaction [$F\,(16, 709) = 3.22$, $p < 0.0001$] were all significant (Figure 7). A *post hoc* Student–Newman–Keuls (SNK) analysis showed that Hong Kong participants (mean SRST = 39.35, S.D. = 15.91) had the fastest search time, followed by the Mainland Chinese group (mean SRST = 45.17, S.D. = 19.12), with the slowest search

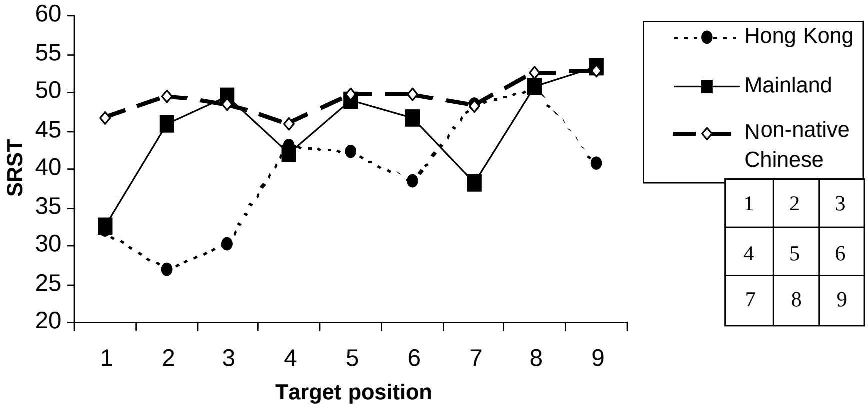


FIGURE 7. Population * Target Position interaction for Square Root Search Time (SRST).

TABLE 1
Simple effects ANOVA of Square Root Search Time (SRST) for each population group (1, 2, 3 correspond to the top target areas; 4, 5, and 6 represent the middle areas; and 7, 8, 9 represent the bottom areas of the target screen)

Population group	*F*- value (df) (Probability)	Student–Newman–Keuls grouping for Target Position† *SRST increases from left to right* (→)
HK Chinese (H)	F (8, 257) = 10.89 (0.0001)***	2 3 1 6 9 5 4 7 8
Mainland Chinese (M)	F (8, 243) = 4.44 (0.0001)***	1 7 4 2 6 5 3 8 9
Non-native Chinese reader (F)	F (8, 209) = 0.29 (0.9704)	4 1 7 3 2 6 5 8 9

†Levels sharing the same underline indicate no significant difference.

being the Non-native Chinese reader group (mean SRST = 49.25, S.D. = 19.88). Word complexity [F (1, 709) = 3.35, $p < 0.0676$], Layout [F (2, 709) = 0.91, $p < 0.402$], and the other interactions were not significant at the $p < 0.05$ level, even though the results showed a significant trend ($0.05 < p < 0.1$) towards word complexity. Simple-effects ANOVA on the Population * Target Position interaction (Table 1) for search time showed a clear pattern and will be discussed later.

3.3. SEARCH PATTERNS

The eye-tracking data revealed useful explanations for the performance results. As expected, there were systematic searches and random searches (Arani, Karwan &

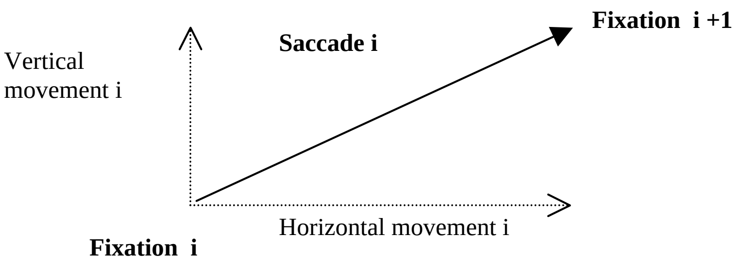


FIGURE 8. Components of the HV-ratio calculation with respect to fixations.

Drury, 1984; Courtney & Guan, 1998). The second author of the paper, manually scrutinized each of the scan patterns and found that the systematic search patterns were dominant (about 90%) than the random (about 10%) search patterns. In the context of the current experiment, a systematic search patterns is one performed row by row or column by column, until the target is found.

The general search strategy was to start at, usually, the top left or top right corner and proceed with the search along that row or column. After finishing that particular row or column, the participants searched the next row or column, respectively.

Eye-scan patterns are generally not quantified and tend to be compared based on visual similarity (Barbur, Forsyth & Wooding, 1993) even though there have been attempts to describe and model successive fixation points using Markov probability matrices (Ellis & Stark, 1986). As a result, a new measure was developed to quantify the search patterns for all correct searches. The quantified variable was denoted as the horizontal-vertical (HV) ratio. The direction of a saccade could be identified based on the coordinates of two consecutive fixations. To determine the HV-ratio, each saccade was divided into a vertical movement and a horizontal movement (Figure 8). The sum of all the absolute values of the vertical movements within a trial corresponded to the total vertical movement. The sum of all the absolute values of the horizontal movements within a trial corresponded to the total horizontal movement. The total vertical movement was then normalized with respect to the height of the search field and the total horizontal movement was normalized by the width of the search field. The ratio of these two quantities was defined as the HV-ratio.

$$\text{HV} - \text{ratio for a trial} = \frac{\Sigma(\text{Horizontal movment } i)/(\text{width of the search field})}{\Sigma(\text{Vertical movment } i)/(\text{height of the search field})}.$$

If the scan pattern of a participant in a particular trial was dominantly horizontal (that was a search performed row by row), the HV-ratio would be greater than 1. If the scan pattern was dominantly vertical (column by column search), the HV-ratio would be low and less than 1. If the scan pattern was a mix of vertical and horizontal searches (combined search), or was random, the HV ratio would tend to be closer to 1. Figure 9 shows an example of a combined search pattern: the participant started with horizontal search and then switched to vertical search after scanning through the screen once. The HV ratio for this example was 1. An example of other derivatives of vertical and horizontal search patterns is shown in Appendix A.

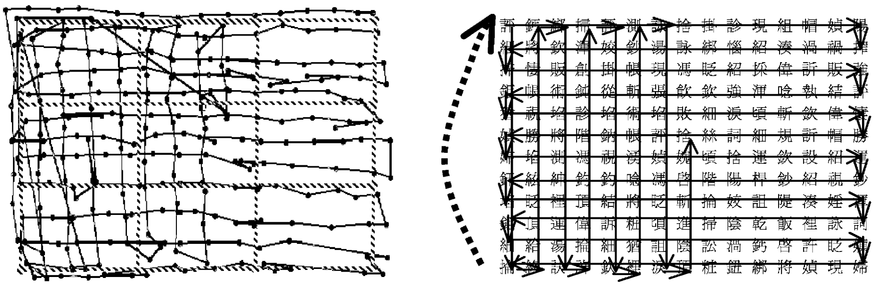


FIGURE 9. Example of a combined search.

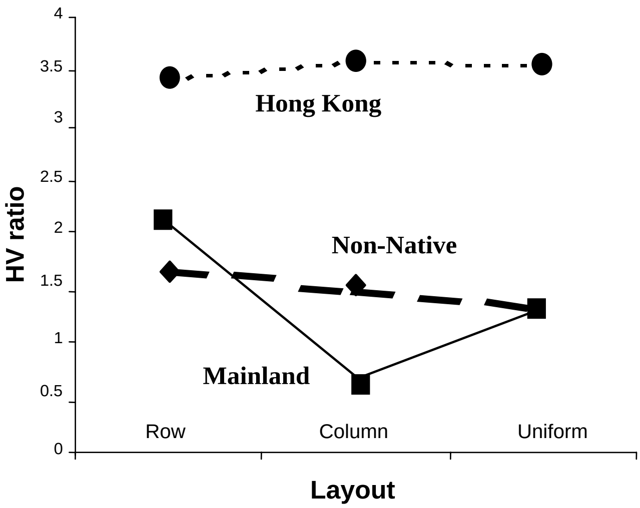


FIGURE 10. Population * Layout interaction for HV-ratio.

A four-way (Population × Layout × Word complexity × Target position) ANOVA on HV-ratio showed a significant effect for Population [$F\,(2, 709) = 118.93$, $p < 0.0001$]. The *post hoc* Student–Newman–Keuls (SNK) analysis showed Hong Kong Chinese (mean HV-ratio = 3.5; S.D. = 2.55) had a significantly higher HV-ratio than both Mainland Chinese (mean HV-ratio = 1.3; S.D. = 1.25) and non-native Chinese readers (mean HV-ratio = 1.5; S.D. = 1.44). There were no differences between Mainland Chinese and non-native Chinese readers. Layout was also significant [$F\,(2, 709) = 4.75$, $p < 0.009$]. The Row layout (mean HV-ratio = 2.4; S.D. = 1.85) had a higher HV-ratio than both Column (mean HV-ratio = 1.9; S.D. = 2.31) and Uniform (mean HV-ratio = 2.1; S.D. = 2.17) separation layouts. The interaction between Population and Layout was also significant [$F\,(4, 709) = 5.49$, $p < 0.0002$]. Figure 10 shows the interaction plot between Population and Layout. All other effects were not significant at the $p < 0.05$ level.

TABLE 2
Simple effects ANOVA of HV-ratio for each Population group (R= Row layout, U=Uniform layout, and C=Column layout)

Population groups	F value (df) (probability)	Student–Newman–Keuls grouping of Layout† *HV-ratio increases from left to right*		
HK Chinese (H)	$F\ (2, 257) = 0.09$ $(p = 0.91)$	R (3.42)	U (3.53)	C (3.57)‡
Mainland Chinese (M)	$F\ (2, 243) = 48.42$ $(p = 0.0001)$***	C (0.5)	U (1.29)	R (2.07)
Non-native Chinese readers (N)	$F\ (2, 209) = 0.88$ $(p = 0.42)$	U (1.29)	C (1.47)	R (1.64)

†Levels sharing the same underline indicate no significant difference.
‡The mean values are in parentheses.

The significant interaction was analysed further. A simple effects ANOVA was performed for each Population group (Table 2). It was found that the three Layouts were not significantly different for HK Chinese and non-native Chinese reader groups. However, Layout showed a significant effect for the Mainland Chinese group [$F\ (2, 243) = 48.21$, $p < 0.0001$], with each of the three layouts being significantly different from each other. For the Mainland Chinese group, the Row layout had the highest HV-ratio (mean = 2.07; S.D. = 1.36). On the other hand, the Column layout had the lowest HV-ratio (mean = 0.52; S.D. = 0.50), and the Uniform separation (mean = 1.29; S.D. = 1.17) had a value between those of the Row and Column layouts.

4. Discussion and conclusions

Interestingly, word complexity did not have any significant effect on accuracy or search time. This shows that word complexity has little or no effect when searching full screen Chinese menus in configurations similar to those used in this experiment. There are many possible reasons for this finding. Reading a complex Chinese word, with a high number of strokes is unlike reading an English word composed of many characters. Once a Chinese word is learnt, its complexity may not have as much effect on the time required to recognize the word. Another potential reason for the lack of a significant effect for word complexity may be related to the chosen levels of complexity. We defined "Low complexity" words as those that had 10–12 strokes and "High complexity" words were those that had 16–18 strokes based on the percentile occurrence in the Chinese dictionary. According to the Chinese dictionary ((Hu-pei tzu shu chu pan she) Han yu ta tzu tien pien chi wei yuan hui, 1989), low complexity words comprise 15–34 percentiles while high complexity words correspond to 60–81 percentiles of the total word distribution. Thus, these two percentiles correspond to relatively low complexity words and those with the above average word complexity. In a previous study related to the identification of Japanese characters (Kanji), Saito (1986) categorized Kanji as low complexity (3–6 strokes), medium complexity (8–11 strokes), and high complexity (13–16 strokes). Even though there are differences between Japanese Kanji and Chinese, character complexity may be similar and the difference between our chosen levels may have been insufficient to show statistical significance even though we used a percentile system to choose the levels. The fact that word complexity showed a trend towards statistical significance ($0.05 < p < 0.10$) partially supports this claim.

As indicated by Wolfe (2000), the "…greatest opportunities for error in visual experiments lie in the creation of stimuli rather than the analysis of the data". For example, preattentive visual processing can affect the efficiency of the search process at varying degrees (Hoffman, 1979; Egeth, Virzi & Garbart, 1984; Wolfe, Cave & Franzel, 1989). In the "preattentive" aspect of visual processing (Neisser, 1967), everything could be processed at once across the visual field. However, it may be impossible for a participant to give a specific response purely based on the preattentive stage (Wolfe, 2000). Only Chinese words with a left–right format (for example 講 for "Talk") were selected. Those Chinese words with a top–down format (for example 葉 for "leaf") were not selected as Chinese words with a left–right format are generally much clearer on a computer display. Besides, words with top–down format have very different shape from those with left–right format. If both formats of Chinese words were used in the search screen, preattentive processing as suggested by Neisser (1967) would be sufficient to distinguish the differences as one may "pop-out" of the display when mixed with the other. Such a "pop-out" phenomena has a subjective quality and only performance measures such as reaction time or accuracy may be able to quantify it (Wolfe, 2000), without measurable aspects to explain its existence. In addition, participants may change their search path if their peripheral vision allowed them to distinguish differing targets without an actual fixation. This could bias the participant search pattern. Therefore, only the left–right format of Chinese words was used in the search screen.

The Layout and the Population * Layout interaction on the both Percent Correct and Search Time were also not significant at the $p < 0.05$ level. This result shows that search performance as measured by per cent correct and search time is not different among the three layouts. Search time is a function of many factors. For the trials with "Hits" on target, the total eye movement is an indirect measure of search time as it relates to the distance that the eye travels from a chosen starting point to target location. The distance travelled depends on the participant's starting position, target position, the layout, and the participant's search strategy. Different combinations among these factors can result in large variations in search time. If the search strategy changed within a trial, it could also contribute to search time. If such variations are not "balanced" (Wolfe, 2000), the differences in search time might be so large as to mask any effect due to Layout.

Search time is affected by the interaction between Target position and Population group. If the target location was close to the starting point, the search time will tend to be lower. Since Target position and Layout were balanced, the interaction between

Target position and Population reflects a difference in search strategy among the three population groups. Grouping based on Student–Newman–Keuls test showed that the search time for the top rows (i.e. target areas 2, 3, 1) had the lowest search time for the Hong Kong Chinese group (Table 1). In addition, the top areas (i.e. areas 2, 3 and 1) were significantly different from areas 4, 5, 7, 8, 9. This shows that Hong Kong Chinese tend to search the top horizontal area first, regardless of the layout of the menu or that these participants tend to show upper field superiority as found by Previc (1996) and Previc and Blume (1993). The search patterns help explain the performance results. The eye-tracking data show that HK Chinese had relatively high HV-ratios in all three layouts (Table 2), implying that the horizontal search pattern was dominant in all three layouts. Ninety per cent of eye movement data show systematic search pattern that start at the top-left corner. Thus it is not difficult to infer that HK Chinese have better performance when the target is present at the top horizontal areas of the search field (that is areas 1, 2 and 3).

On the contrary, the Mainland Chinese group had the lowest search time for the leftmost columns (i.e. target areas 1, 7, 4) (Table 1). Area 1 has significantly lower search time than areas 2, 3, 5, 6, 8, 9, but area 4 was not different from any of the other target areas. This result may imply that Mainland Chinese use the left top area of the menu to start the search without a predictable search pattern or alternatively the Mainland Chinese group exhibits upper left-field superiority as suggested by Previc (1996) and Previc and Blume (1993). The significantly different HV ratios among the three layouts are an indicator that the search strategy of Mainland Chinese is different depending on layout. For the Row layout, Mainland Chinese used horizontal search patterns and in the Column layout, they used more vertical search (HV-ratio <1 has been regarded as a vertically dominant search pattern), and for the Uniform Separation layout, Mainland Chinese had HV-ratios that are in-between the value of other two layouts. As a result of this changing search pattern, Mainland Chinese had significantly better performance only on target area 1 (top left area), which is a common starting position for horizontal and vertical scan patterns.

These results are in good agreement with the Shih and Goonetilleke (1998) study for 1-row and 1-column menus where Hong Kong Chinese participants showed a faster search when using a horizontal menu. In that study, the participants were "forced" to adopt a vertical or horizontal scanning pattern as the experiment was designed to be that way. Hence, time differences were very evident. The present study also indicates that the "natural" search pattern for Hong Kong Chinese is predominantly horizontal. The scanning patterns, however, were not restricted to one type. The participants were able to adopt whatever they felt was suitable to complete the task. Hence, it is not surprising, that the Mainland Chinese change their search pattern depending on the layout. In Mainland China, most published information follow the "Z" pattern. According to the matrix transposition rule proposed by Shih and Goonetilleke, the reading orientation implies that Mainland Chinese should have a better search performance with a vertical menu. Even though the search time results did not show such an effect, the eye movement data show that Mainland Chinese favoured a vertical search.

The search time results of non-native Chinese readers did not show any difference among the nine target positions. The HV ratio result of this group also had no significant difference among the three layouts. For this group of participants, the HV-ratio is around 1, implying that the non-native Chinese reader group, in general, had no preference towards a horizontal or vertical search pattern in all three layouts.

The differing search strategies of the three population groups resulted in a statistically significant interaction between the "Population" and "Layout" for HV ratio. It is reasonable to assume that this search strategy difference is the primary cause for the significant interaction of Target position*Population for search time.

The differences in strategies between the two Chinese groups may be due to many different factors. Some of which are as follows.

1. Differences in reading materials: Newspapers and magazines in Hong Kong are printed in a vertical orientation. The reading materials in Mainland China are a mix of both orientations and as a result Mainland Chinese adopt a pattern depending on the stimulus material.
2. Another possibility may be related to the differences in computer usage. The software packages that are frequently used in Hong Kong include Microsoft Office and Windows-based software, which generally have a horizontal structure in their menu layouts. The Mainland Chinese participants generally had less computer experience than HK Chinese before arriving in Hong Kong, and therefore, may have chosen a search pattern based on the implicit reading pattern.
3. A third reason may be related to the nature of the stimulus material. Mainland Chinese participants may not have been fluent with the complex characters that were used in the test even though they were familiar with them. Thus, they may have attempted to "read" rather than search and as a result may have followed a reading pattern. In other words, material having a context may be better positioned in a reading pattern. Information that is non-contextual or are independent of each other may be best placed in a transposed setting for effective visual search, as suggested by Shih and Goonetilleke (1998).

For interfaces similar to the ones tested, search time may be reduced if the important information is located on the top left. For more efficient use of the full screen menu, it may be appropriate to consider horizontal layouts for Chinese. Hong Kong Chinese have a horizontal scan pattern, and the Mainland Chinese tend to show flexibility in their search patterns depending on the layout. Thus, in general, a search structure that favours a horizontal search pattern may seem appropriate for Chinese even though further study is still required.

This work was funded by a HKUST Direct Allocation Grant (DAG99/00.EG14).

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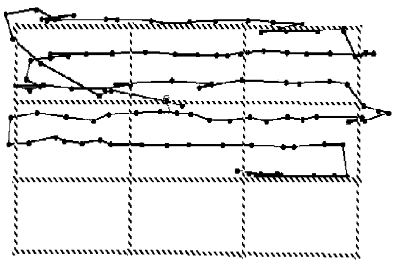
Paper accepted for publication by Associate Editor, Dr. K. S. Eklundh.

Appendix A: Examples of search patterns

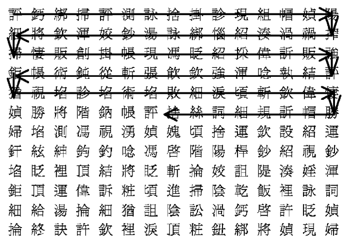
HORIZONTAL AND VERTICAL ZIGZAG

Characteristic: scanned row by row or column by column, moving to next row/column at nearrest ending in a Zigzag pattern. These were the most abundant search patterns, with over 80% of systematic search patterns belonging to this format.

Horizontal Zigzag (HV ratio = 2.8)

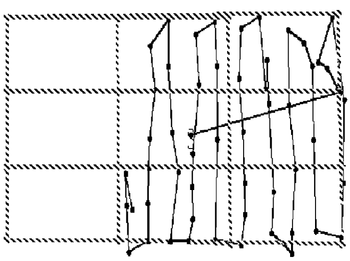


Eye movements

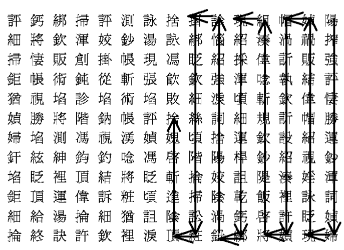


General pattern

Verical Zigzag (HV ratio = 0.17)



Eye movements



General pattern