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Structure Detection of Chinese Characters: Visual Search Slope as an Index of Similarity between Different-Structured Characters

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Three visual search experiments were conducted to examine the effect of the configurational structures of Chinese characters on search efficiency. In Experiment 1, the subjects' task was to detect a different character among a homogeneous set of distracting characters presented in an imagery 5 × 5 grid. The set size varied from trial to trial, and the reaction times were measured. The target and the distractors either shared the same structure or had different structures. The horizontal-vertical and open-enclosed structural dimensions that were revealed in the character space of Yeh, Li, and Chen (1997; 1999) were examined. In Experiment 2, the subject searched for a predesignated target character among a distracting field of constant density. Better controls of the familiarity of same-structured and different-structured trials and the range of character frequency were made to exclude the possible confounding variables in Experiment 1. The results from both experiments showed that it was more efficient to detect a target character when its structure was different from that of the distractors than when their structures were the same. In Experiment 3 the five structure types explicitly specified in Yeh et al. (1999) were paired as the target and distractors. As the structures between these pairs were more similar, the search slopes were steeper. The search slopes thus were served as a diagnostic tool for the similarity of characters with various structures. Implications of these results were discussed in the text.

Keywords: Chinese character, Structure, Similarity, Visual search

Chinese characters are the basic unit of Chinese script. Physically, each character occupies roughly the same size in space, and is separated from other characters by a blank space. Though in the long history of the development of Chinese writing system characters had undergone various transformations before they reached the current forms, the origins of their formations were mostly taken from the shapes of objects or the meanings of events. Therefore, the graphic form of a character may bear a more direct relationship to its meanings than that of an alphabetic word.

The ultimate goal for most researchers in the field of reading is to understand the very complicated yet seemly effortless task of reading text. There are various levels of analysis that can be performed to achieve this goal, and the reduction to single character recognition is only one of them. Even for single character recognition, however, most studies have emphasized on the relationship between phoneme and meaning, ignoring grapheme or the graphic aspect of a character. For example, the graphic form of a character

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is widely treated only as a medium to get to either the sound, or the meaning, or both. This is a somewhat unbalanced view, as grapheme, phoneme and meaning are the three intimately related aspects in visual character recognition.

Consequently, although the demand for using Chinese characters as experimental stimuli has been increased as the issue of character recognition has become more and more appealing to many researchers, the representation and processing of the graphic forms of Chinese characters have yet to be worked out. A character is by no means only a simple shape. It is well structured. A character's structure is characterized by the arrangement of various parts at different locations. Although nowadays Chinese characters are not purely "graphical" as they originally were, it is very likely that structural information is extracted and used by a skilled reader to enhance the recognition process. To say the least, if the structural information can be used, the perceptual load for processing characters can be reduced.

How many kinds of constituent structures are there in the population of Chinese characters, then? According to a statistic, the total number of different structure types may exceed 15 (Fu, 1985). Besides the statistics, researchers who are interested in the psychological processes related to reading Chinese often have to classify Chinese characters into various groups in order to choose representative samples from each group. For example, Yeh and Liu (1982) classified characters into 2 groups: horizontal-vertical and symmetric-asymmetric. Liu and Yeh (1977), and also Liu, Zhang, and Young (1979), classified three-component characters into horizontal-3, vertical-3, left-1-right-2, left-2-right-1, upper-2-lower-1, and upper-1-lower-2. Liu (1984) further classified all characters into 11 groups, including inseparable, left-right balanced, left-dominating, right-dominating, upper-lower balanced, upper-dominating, lower-dominating, completely enclosed, upper-left enclosed, left-lower enclosed, left-upper-right enclosed, and upper-left-lower enclosed. Chan (1992) put them into 16 categories, taking into consideration the relative positions of the radicals.

All those categorizations were made based on the practical needs of particular studies, thus reflecting the experimenters' personal knowledge, which might not be the same as that in subjects' minds. To directly tackle this issue and examine the character classification system empirically, Yeh, Li, and Chen (1997) asked their subjects to classify Chinese characters according to the degree of similarity in their shapes. The similarity matrices obtained from the sorting task were then submitted to multidimensional scaling (MDS). The results showed that Chinese readers tended to classify Chinese characters by their composite structures. The X and Y axes of the character space derived from MDS could be interpreted as horizontal-vertical and open-enclosed structures, which accounted for more than 95% of the variance. These two axes were assumed to reflect the underlying perceptual dimensions in the classification of Chinese characters.

In the original study of Yeh et al. (1997), an equal number of the sample characters for each of the seven predesignated categories adopted from Chan (1992) were selected as the stimuli of the sorting task. To examine whether the classification scheme would be affected by using different predesignated categories and varied sample sizes, Yeh, Li, and Chen

(1999) in a follow-up study selected as the stimuli an unequal number of the sample characters for each of the 12 predesignated categories adopted from another source (Liu, 1984). The results again confirmed the horizontal-vertical and open-enclosed structures as the two major axes in the character space. Furthermore, hierarchical cluster analysis revealed five distinct clusters in the form of (H, L,V, P, E), where H, L, V, P, and E represents Horizontal (e.g., 印), L-shaped (e.g., 返), Vertical (e.g., 念), P-shaped (e.g., 序), and Enclosed (e.g., 固 or 匯) structures, respectively.

As all other classification systems in every scientific area, the function of establishing a classification scheme such as that in Yeh et al. (1997; 1999) is to systematize the highly complicated variation of character shapes. Such a classification system is a prerequisite for further investigation and for new theories to develop upon. Most importantly, unlike other character categorizations mentioned above, it is based on empirical data obtained from quite a number of subjects across different conditions. The consistency of these data thus provides solid grounds for research along this line.

Put it in this context, we report in this study one piece of converging evidence regarding the structure detection of Chinese characters. In our earlier attempts, the underlying structural dimensions were inferred from the performance in the sorting of the character shapes without time pressure. Two concerns could be raised regarding to the generality of this categorization. First, using a sorting task the subjects could view the character stimuli as long as they would like to, which inevitably would involve decisions and strategies that would not be used in the normal character recognition and/or reading processes. Second, it is doubtful that whether the structural dimensions obtained by explicitly asking the subjects to judge the shapes of the characters can also be applied to the situation when no such request was made. The main purpose in this study was then to use a visual search paradigm to answer these questions.

In visual search, the subject's task is to search for a designated target within various numbers of distractors as quickly and accurately as possible. The set size varies from trial to trial, and the target is usually present half of the time. Changes in reaction time with set size presumably reveal the processing of the target and/or the distractors in the visual system. Different search speeds derived from the RT slopes were assumed to reflect parallel or serial processing of visual information (Treisman & Gelade, 1980; Treisman & Gormican, 1988). The differences between the features of the targets and distractors is thought to be the trigger that determines which mode of processing will be used. For example, to search for a tilted line among vertical lines can be very easy and the reaction times vary little, if any, with the total number of items used in the display (Treisman, 1985; Treisman & Gormican, 1988). The slope of the RT vs. set size function approaches zero, and a parallel search is assumed for such a feature search task. However, a green O among red Os and green Xs is not so easily detected. In this situation, RT is a linear function of the set size, which presumably reflects a serial search process of such a conjunction search task (Treisman & Gelade, 1980). In the former case, the difference between a tilted line and vertical lines is one feature: line orientation. In the latter case the target (green O) is a combination of the features from two kinds of distractors: "green" from green Xs and "shape (O)" from red Os. Such differences in the RT slopes have been argued to reflect the preattentive and attentive modes in visual information processing (Neisser, 1967; Treisman & Gelade, 1980; Treisman & Souther, 1985; Treisman, 1985; 1986). In addition, the linear increase in RT and the 2:1 ratio between the slopes of target-absent and target-present trials is assumed to be characteristic of a serial, self-terminating search (e.g., Treisman & Gelade, 1980).

Challenges arise, however, to such dichotomies of feature search vs. conjunction search, parallel processing vs. serial processing, and preattentive mode vs. attentive mode. For example, it has been argued that the 2:1 ratio for target-absent and target-present slopes does not necessarily define the serial and self-terminating operation mode, because the possibility of a limited-capacity or noisy parallelism cannot be excluded (Townsend, 1971; 1990). Furthermore, statistics show that most of the ratios found exceed 2, the precise value depending on the tasks performed (Wolfe, 1998). More importantly, many conjunction searches have been found to be more efficiently processed than would be predicted using a strictly serial search (e.g., Cohen, 1993; Cohen & Ivry, 1991; McLeod, Driver, & Crisp, 1988; Nakayama & Silverman, 1986; Sagi, 1988; Theeuwes & Kooi, 1994; Treisman & Sato, 1990). Consequently, several models have been proposed to argue against the dichotomy of serial vs. parallel processing, favoring the idea of a continuum of search efficiency (e.g., Duncan & Humphreys, 1989; Nakayama, 1990; Wolfe, Cave, & Franzel, 1989; Wolfe, 1994; 1996).

Following this, our goal in this study did not aim at whether the structure detection of Chinese characters can be made preattentively, but rather to focus on the search efficiency reflected in the RT slopes, and to take the slope values to infer the similarity relationships between target characters and distractors. All of the characters used here were legal Chinese characters composed of a limited (usually small) number of strokes that were combined in different ways. Therefore, only the spatial arrangements of these strokes, and thus the structures, were different among targets and distractors. Such a spatial configuration search was predicted to have RT slopes greater than zero (Wolfe, 1998).

To start with, in Experiment 1 we first examined the horizontal-vertical and open-enclosed structural dimensions by asking the subject to find a different character among a set of homogeneous distracting characters. The target and the distractors either had the same structure or with different structures. The critical prediction was that the RT slope in the *different-structured* condition would be shallower than the slope in the *same-structured* condition, an inference drawn from the hypothesis that detecting characters with different structures would be easier than discerning between characters with the same structure. This prediction was indeed confirmed by the results of Experiment 1.

To exclude the possible confounding variables that may have contributed to the results, better controls of the familiarity of same-structured and different-structured trials and the range of character frequency were made in Experiment 2. Although results from the "looking-for-a-different-one" paradigm as in Experiment 1 have usually been discussed under the same theoretical framework as those from the standard visual search paradigm (e.g., Bergen & Julesz, 1983; Sagi & Julesz, 1985), the RT curves we obtained in Experiment 1 were negative accelerated, best fit by a power function, rather than a linear one as usually found in the visual search literature. To be comparable with the classical visual search reports, in Experiment 2 we used a visual search paradigm with a predesignated target presented among equal spacing distractors. The RT curves turned into linear after such manipulations, nevertheless, the critical result was still found as in Experiment 1: the search efficiency was higher in the *different-structured* condition than that in the *same-structured* condition.

After it was established that the two structural dimensions were indeed detected and used in the search process, in Experiment 3 we moved one step forward to test the five distinct structure categories (H, L, V, P, E) explicitly stated in Yeh et al. (1999). The RT slopes of the 10 target-distractor pairs formed by these five structures were then compared to obtain the various degree of similarity between characters with different structures. Since the difference in the RT x set size slopes can be explained by the similarity relationship between targets and distractors (Duncan & Humphreys, 1989), as the target and distractors are more similar, the search slopes should go steeper. We adopt this model and take the value of the RT slope as the index of the similarity between different character structures.

Experiment 1

The purpose of Experiment 1 was to examine whether the two structural dimensions: horizontal-vertical and open-enclosed, revealed in the two axes of the character space in Yeh et al. (1997; 1999), would show a different processing efficiency as measured by the changes in RT with set size. If the two structural dimensions of Chinese characters are indeed salient for skilled Chinese readers, we should expect to find faster search rate when the structure of the target is different from that of the distractors (*different-structured condition*), as compared to when both share the same structure (*same-structured condition*).

Methods

Subjects. Twenty-four undergraduate students from several universities in Taiwan were recruited from the Internet (BBS) and paid NT$400 for voluntarily attending the experiment for 4 hours. All had normal or corrected-to-normal vision. None had ever participated in any of the related experiments on Chinese characters designed by the author.

Stimuli and Design. For the Horizontal-Vertical (H-V) structural dimension, six Chinese characters all with a stroke number of 8 were chosen as the stimuli. Half of the characters, 怕 (pa4), 拒 (ju4), 板 (ban3) belonged to the horizontal structure, and the other half, 享 (xiang3), 宗 (zhong1), 念 (nian4) belonged to the vertical structure. These characters were Cu-Hei font, extended to 32 × 32 pixels on the screen.

For the Open-Enclosed (O-E) structural dimension, another set of six Chinese characters all with a stroke number of 8 was chosen as the stimuli. They were 夜 (yie4), 卦 (gua4), 念 (nian4) (open-structured), and 固 (gu4), 周 (zhou1), 函 (han2) (enclosed-structured). These candidates were chosen to cover a large variance within the two main structures. For example, within the open-structured class, 夜 is a character with 3 components in a one-upper, two-lower form, and 卦 and 念 are horizontal- and vertical-structured, respectively. Within the enclosed structure, the three characters 固, 周, and 函 have different types of enclosures, i.e., complete, left-upper-right and left-down-right. Consequently, the occurrence frequencies for these characters ranged more widely than those in the H-V dimension (see Appendix). Experiments with characters in these two structural dimensions were conducted separately by different groups of subjects, with an equal number of subjects for each structural dimension.

An IBM compatible Pentium PC was used for stimulus presentation and response recording. At a viewing distance of 115 cm, each character was extended at a visual angle of about 0.69° × 0.69°. The subjects sat in a dimly illuminated experimental chamber and were tested individually. During the experiment, a chin rest was used to fix their head positions so that the center of the display was kept at about their eye level. They were asked to respond by pressing two keys on a regular keyboard. The assignment of a YES or NO response to these two keys was counterbalanced across subjects. Throughout the experiment, the index and middle fingers of their right hand rested on the two response keys.

The characters were shown in an imaginary 5 × 5 grid. Each cell in this grid extended 64 × 64 pixels. Each character was located randomly within a cell with the only constraint that its entire shape would be within the boundary of a single cell. For the 6 stimulus characters, each with an equal chance to be a target (or distractor), there were 6 × 5 = 30 pairs, consisting of 30 display types. For each display type, there were five set sizes: 3, 6, 12, 18, 24, each repeated 20 times, with an equal number of target-present and target-absent trials. The 100 trials for each display type were presented within a block. In a single block of 100 trials, five set sizes and two response types (YES for target-present trials and NO for target-absent trials) consisted of a complete set of 10 trials, presented in a random order and repeated 10 times. There were thus 3000 trials in total. A random presentation order was used for the 30 blocks. Three factors (structure, set size, presence) were all within-subjects designs.

Procedure. In each trial, a plus sign as the fixation pattern was first shown for 500 ms, followed by the stimulus display after a 100 ms blank screen interval. The stimulus display stayed on the screen until the subject pressed the response key. A beep sound appeared before the stimulus display to signal its forthcoming. Another beep with different pitch would be presented after the stimulus display if an incorrect response was entered. The inter-trial interval was set at 1 sec. Forty practice trials were run before the experiment, and characters used in the practice trials were different from those in the experiment. Figure 1(A) shows some examples of the stimulus display.

The subjects came in the lab on separate days to finish the entire experiment. Their task was to indicate "accurately and as quickly as possible" whether or not a different character was present in the display. To ensure high enough accuracy, at the completion of every session of 20 trials, a statistical presentation on the mean RT and accuracy was shown. The subjects were informed at the beginning of the experiment that any 20-trial session with an error rate higher than 10 % would be discarded and the entire session would be rerun again. No data from the discarded sessions would be recorded. Trials with reaction times that were either too fast (< 150 ms)

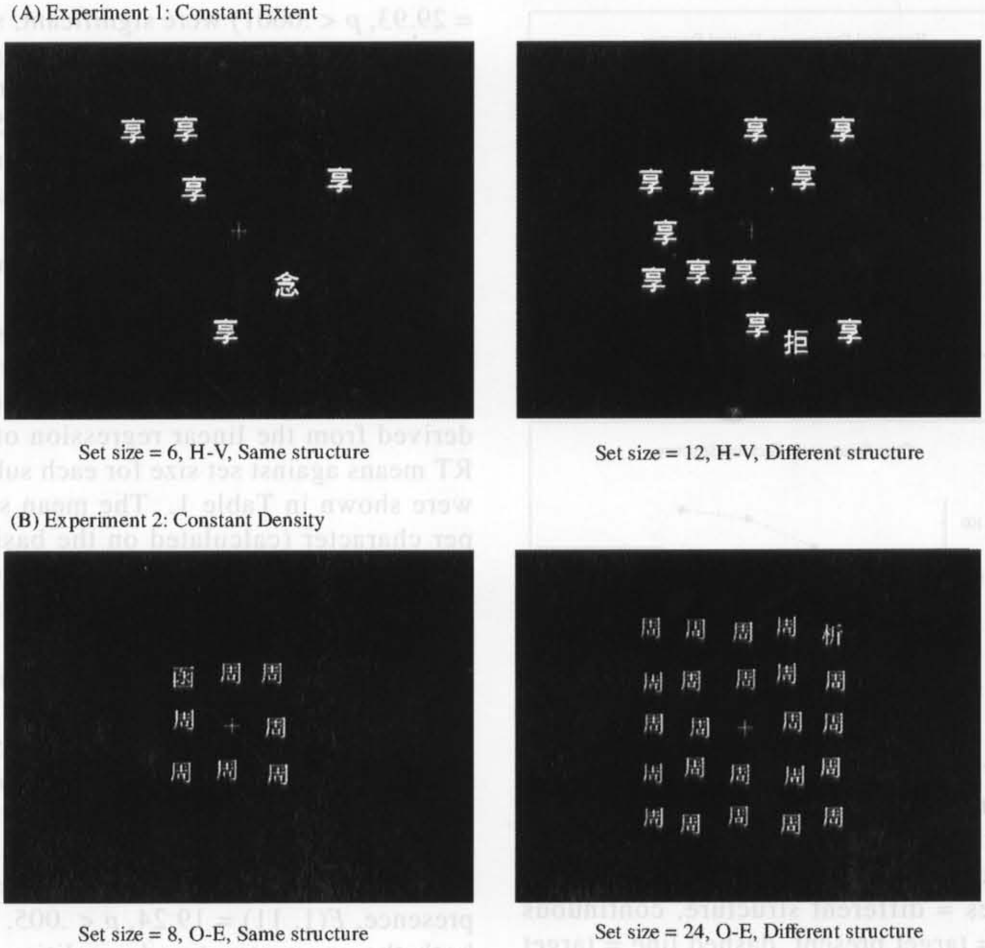


Figure 1. Stimuli used in this study.

or too slow (> 5 sec) were treated as errors as well.

Results

Horizontal vs. Vertical Structure

The error rates were low under all conditions, being less than 6% on average, and thus, only the reaction time data were analyzed in detail. The mean reaction times for correct trials from each subject were calculated for each display type at each set size by presence. The RTs for all display types were then collapsed into the two critical conditions to be examined: *same-structured condition* and *different-structured condition*. The top panel of Figure 2 shows the averages across subjects for the target-absent trials and target-present trials in these two conditions.

A three-way within-subjects analysis of variance (ANOVA, Chen & Cheng, 1999) on the RTs with the factors of condition, set size, and presence was carried out. There were main effects on condition ($F(1, 11) = 31.54$, $p < .0005$), presence ($F(1, 11) = 45.73$, $p < .0001$), and set size

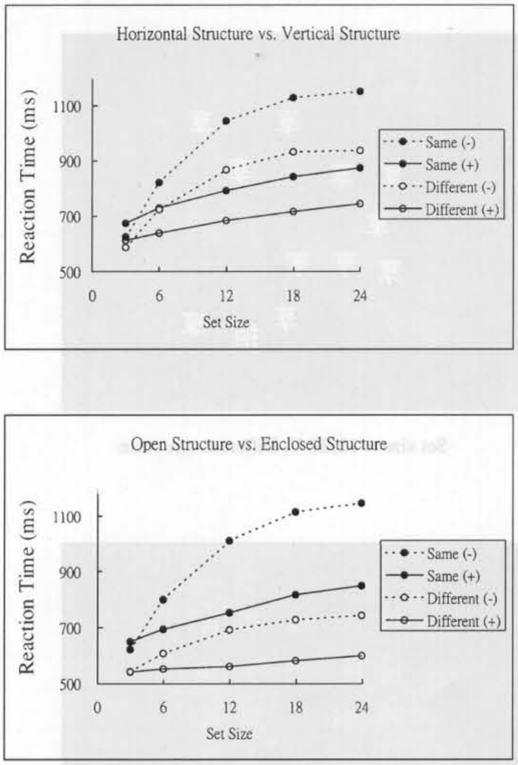


Figure 2. Mean correct reaction time as a function of the set size in Experiment 1. Closed circles = same structure, open circles = different structure, continuous line = target present, dashed line = target absent.

($F(4, 44) = 51.28$, $p < .0001$). Trend analysis of set size shows that both linear trend ($F(1, 44) = 183.37$) and quadratic trend ($F(1, 44) = 20.95$) were significant, $ps < .0001$. The two-way interactions of condition and presence ($F(1, 11) = 23.96$, $p = .0005$), condition and set size ($F(4, 44) = 21.68$, $p < .0001$) , and presence and set size ($F(4, 44) = 37.75$, $p < .0001$), and the three-way interaction of condition, presence and set size ($F(4, 44) = 12.67$, $p < .0001$) were all significant. The simple main effects of set size at same-structured condition ($F(4, 88) = 67.48$, $p < .0001$) and at different-structured condition ($F(4, 88) = 29.93$, $p < .0001$) were significant, so as the simple main effects of set size at target-present trials ($F(4, 88) = 11.01$, $p < .0001$) and target-absent trials (F $(4, 88) = 85.00$, $p < .0001$). Both linear and quadratic trends of set size at the same-structured, different-structured, target-present and target-absent trials were all significant, $ps < .001$.

What is more interesting here is the comparison of the RT slopes across different conditions. The search slopes derived from the linear regression of the RT means against set size for each subject were shown in Table 1. The mean slope per character (calculated on the basis of individual slope estimates) was 16.81 ms/item in the same-structured condition, which was significantly higher than that in the different-structured condition (11.23 ms/item), $F(1, 11) = 25.93$, $p < .0005$. The mean slope for the target-absent trials (20.25 ms/item) was higher than that for the target-present trials (7.79 ms/item), $F(1, 11) = 37.31$, $p = .0001$. There was also an interaction effect of structure and presence, $F(1, 11) = 19.24$, $p < .005$. For both the same-structured condition and different-structured conditions, target-absent trials have higher slope values than target-present trials, $Fs(1, 22) = 49.94$ and 22.05, respectively, $ps < .0001$. For target-present trials, significantly higher slope values were found in the same-structured condition than in the different-structured condition (9.33 vs. 6.26 ms/item), $F(1, 22) = 6.17$, $p < .05$, same for the target-absent trials (24.30 vs. 16.21 ms/item), $F(1, 22) = 42.83$, $p < .0001$. The mean absent/present ratio was 2.60 in the same-structured condition, while it was 2.59 in the different-structured condition.

In Figure 2, the best curve fitting was obtained when the set size was transformed logarithmically and then submitted for

Table 1
Slope and slope ratio of indivisual subject in Experiment 1

(A) Horizontal-Vertical Structure

	Same-Structured Condition				*Different-Structured Condition*			
Subject	Present	Absent	Mean	Absent/Present	Present	Absent	Mean	Absent/Present
s1	10.87	28.24	19.55	2.60	6.69	22.59	14.64	3.38
s2	9.91	15.35	12.63	1.55	5.78	10.49	8.13	1.82
s3	7.97	18.93	13.45	2.38	3.38	11.36	7.37	3.36
s4	3.50	13.83	8.66	3.95	4.27	10.67	7.47	2.50
s5	6.65	25.59	16.12	3.85	3.82	11.09	7.46	2.90
s6	6.35	20.07	13.21	3.16	4.45	16.76	10.61	3.77
s7	8.92	22.69	15.81	2.54	8.36	17.55	12.96	2.10
s8	9.38	28.31	18.84	3.02	6.74	18.68	12.71	2.77
s9	13.81	37.64	25.73	2.73	8.23	24.57	16.40	2.99
s10	5.32	8.39	6.85	1.58	4.08	6.03	5.05	1.48
s11	21.57	55.85	38.71	2.59	13.14	35.07	24.10	2.67
s12	7.70	16.69	12.20	2.17	6.16	9.61	7.88	1.56
Mean	9.33	24.30	16.81	2.60	6.26	16.21	11.23	2.59

(B) Open-Enclosed Structure

	Same-Structured Condition				*Different-Structured Condition*			
Subject	Present	Absent	Mean	Absent/Present	Present	Absent	Mean	Absent/Present
s1	4.78	17.13	10.95	3.58	1.51	5.40	3.46	3.57
s2	7.07	19.43	13.25	2.75	0.77	2.74	1.75	3.55
s3	8.71	21.18	14.94	2.43	2.52	6.45	4.49	2.56
s4	10.45	25.27	17.86	2.42	3.43	12.99	8.21	3.79
s5	11.11	37.64	24.37	3.39	3.36	18.17	10.77	5.41
s6	10.61	20.72	15.66	1.95	3.74	3.48	3.61	0.93
s7	12.97	28.51	20.74	2.20	3.09	11.38	7.24	3.68
s8	8.92	14.89	11.91	1.67	1.78	8.58	5.18	4.82
s9	15.58	45.35	30.46	2.91	5.41	26.61	16.01	4.92
s10	9.52	25.84	17.68	2.72	3.17	6.38	4.78	2.01
s11	9.18	23.53	16.36	2.56	2.97	5.87	4.42	1.97
s12	4.87	10.76	7.81	2.21	0.58	4.26	2.42	7.41
Mean	9.48	24.19	16.83	2.55	2.69	9.36	6.03	3.48

linear regressions, which accounted for 99.39% variance in the same-structured condition and 99.42% in the different-structured condition. Comparisons of the RT × log (set size) slope for each subject also arrived at the same results: significantly higher slope values were found in the same-structured condition than in the different-structured condition for target-present trials, target-absent trials, and when collapsed over target-present and target-absent trials.

Open vs. Enclosed Structure

Again, the error rates were in general quite low under all conditions and the grand mean was lower than 6%. The RT averages across subjects for the target-absent trials and target-present trials in the same-structured and different-structured conditions were shown in the bottom panel of Figure 2. Slope and slope ratio of individual subject were shown in the bottom panel of Table 1. An ANOVA on the RTs with the factors of condition, set size, and presence indicated that there were main effects on condition ($F(1, 11) = 262.36, p < .0001$), presence ($F(1, 11) = 59.17, p < .0001$), and set size ($F(4, 44) = 61.70, p < .0001$). Trend analysis of set size shows that both linear trend ($F(1, 44) = 229.21$) and quadratic trend ($F(1, 44) = 17.15$) were significant, $ps < .0005$.

Two-way interactions of condition and set size ($F(4, 44) = 123.26, p < .0001$), presence and set size ($F(4, 44) = 38.50, p < .0001$), and condition and presence ($F(1, 11) = 52.93, p < .0001$) were all significant. A three-way interaction of condition and presence and set size was also significant, $F(4, 44) = 32.72, p < .0001$. The simple main effects of set size at target-present ($F(4, 88) = 11.65, p < .0001$) and target-absent ($F(4, 88) = 98.29, p < .0001$) trials were both significant, so as the simple main effects of set size in the same-structured condition ($F(4, 88) = 120.74, p < .0001$) and in the different-structured condition ($F(4, 88) = 15.21, p < .0001$). Both linear and quadratic trends for the four curves in the bottom panel of Figure 2 were significant, $ps < .05$.

As to the search slopes, a significantly higher mean slope in the same-structured condition (16.83 ms/item) than in the different-structured condition (6.03 ms/item) was obtained, $F(1, 11) = 163.16, p < .0001$. The mean slope for the target-absent trials (16.77 ms/item) was higher than that for the target-present trials (6.09 ms/item), $F(1, 11) = 34.32, p = .0001$. There was also an interaction effect of structure and presence, $F(1, 11) = 46.51, p < .0001$. For both the same-structured and the different-structured conditions, target-absent trials have higher slope values than target-present trials, $F(1, 22) = 58.85, p < .0001$, and $F(1, 22) = 12.09, p < .005$, respectively. For both target-present and target-absent trials, significantly higher slope values were found in the same-structured condition than in the different-structured condition, $F(1, 22) = 43.31$ (9.48 vs. 2.69 ms/item) for the former, and $F(1, 22) = 206.75$ (24.19 vs. 9.36 ms/item) for the latter, $ps < .0001$.

The best curve fitting was obtained, as with the H-V structural dimension, when the set size was transformed logarithmically and then submitted for linear regressions, which accounted for 99.66% variance for the same-structured condition and 99.80% for the different-structured condition. There were significant differences in the slopes between the same-structured condition and the different-structured condition (collapsed over the target-present and target-absent trials), $p < .0001$. The slopes differed significantly between the target-present trials and the target-absent trials for both the same-structured condition ($p < .05$) and the different-structured condition ($p < .0001$).

Discussion

The search for a different Chinese character among distracting characters was more efficient when the target and the distractors differed in their structures than when they shared the same structure. For example, searching for a horizontal-structured character among vertical-structured characters (or vise versa) was more efficient than searching among same-structured characters. Also, searching for an open-structured character among enclosed-structured characters (or vise versa) was more efficient than searching among same-structured characters. These results confirmed our prediction that both the H-V and O-E structural dimensions indicated by the character space in Yeh et al. (1997; 1999) can be detected and used to help in the search process. In addition, the structural difference between O-E seems to be larger than that between H-V, so as to yield a faster search rate in the O-E dimension compared to that in the H-V dimension. The mean slopes for the O-E dimension were under 10 ms/item for both the target-present trails and the target-absent trials.

Several confounding variables may have contributed to the above results, though. First, there were more trials in the different-structured condition than that in the same-structured condition. Take the H-V dimension as an example. Each of the six character stimuli, H1, H2, H3 and V1, V2, V3 was used equally often, so that when one was served as the target, the others all would be served as distractors. In such a design, however, the number of trials in the same-structured condition would be only 2/3 of that in the different-structured condition (H1-H2 and H1-H3 compared to H1-V1, H1-V2, and H1-V3, when H1 was the target). It was possible that as the experience with these different-structured trials was increased, the search efficiency would be increased accordingly, since search performance does improve with practice (Schneider & Shiffrin, 1977).

Second, to cover a large structure variance within the O-E dimension the characters selected thus covered a wider range of occurrence frequencies as compared to that in the H-V dimension. This should not affect the within-dimension comparison between the same-structured and different-structured trials. It might, however, lead to the faster search rate obtained in the O-E dimension compared to that in the H-V dimension, if increasing the frequency difference between the target and the distractors would make the detection of the target easier.

Another point to note is that for the RT curves the best fit was found that the RTs increased linearly with logrithmic transforms of the set size. This means that as the set size increased, the processing time for each item decreased, or the processing unit (in terms of the number of stimulus in the display) enlarged. This is in variance with the usually found linear curves in the visual search literature. Two reasons may account for the difference in the curve shapes. First, rather than searching for a predesignated target as in the standard visual search task, in this experiment the subjects were asked to detect a different character among a homogenous background. Such an odd-man-out paradigm may lead to a power RT function, rather than a linear one. Although this possibility cannot be excluded, we doubt the difference in the task may really cause any substantial difference in the RT curve shape since a blocked presentation was used here, which would reduce the difference between the conditions with and without a predesignated target. This can be seen from the comparison of the same-structured condition and the different-structured condition for the target-absent trials. There should have been no difference in the target-absent trials for these two conditions if there had no top down influence existed, since the display patterns were all consisted of only one kind of characters. The finding of a faster search rate for the different-structured condition also in these negative trials indicated the working of mental set within a time frame of a single block. When the same target-distractor pairs were repetitively presented in a block of trials, a strategic search for a possible target would be able to develop during the course. The second, and the more likely, reason for the obtained power function in this experiment was the arrangement of the display pattern. In this experiment, various numbers of character stimuli were all presented within a 5×5 grid, making the stimulus density increased with the number of items. This may lead to the increase of the possibility to process more than one item at a time as the set size increased.

In consideration of these, in Experiment 2 an equal number of trials in the same-structured and different-structured conditions was presented, and the O-E characters were chosen to cover a narrower range of occurrence frequency to be comparable with that in the H-V dimension. Furthermore, a visual search task with a predesignated target and a constant density display was used to see whether a linear curve as shown in the visual search literature would also be obtained.

Experiment 2

Methods

Subjects. Eighteen undergraduate students were separated into two groups to conduct the experiment in the H-V dimension and the O-E dimension respectively. Ten students were recruited from the subject pool of the Department of Psychology at National Taiwan University to conduct the H-V experiment. Another group of eight students was recruited using advertisement on the Internet (BBS) and paid NT$200 for voluntarily attending the O-E experiment. All had normal or corrected-to-normal vision, and were naive about the purpose of this experiment. None had ever participated in the previous experiment.

Stimuli and Design. For the H-V structural dimension, the same characters and fonts as in Experiment 1 were used. For the O-E structural dimension, however, the three open-structured characters used in Experiment 1 were replaced by 妻 (qi1), 析 (xi1), and 俊(jun4). The six O-E characters were Zhong-Ming font. All these characters were chosen in the frequency count of 1,500-4,500 from the Corpus-Based Frequency Count of Characters in Journal Chinese (Academic Sinica, Taipei, 1993). See Appendix for the exact frequency count of each character.

The display contained 1, 8, or 24 characters arranged in an imagery grid of 3×3 or 5×5. Each cell in these grids extended 64×64 pixels. The central cell was always occupied by the fixation pattern, a plus sign. Each character was extended 32×32 pixels and was located at a random location within a cell. Its entire shape would never exceed the boundary of a single cell. For the display of set size 1, the only character would be randomly appeared in any one of the cells of the 3×3 grid. For displays of set sizes 8 or 24, every cell of the 3×3 or 5×5 grids was occupied, as shown in Figure 1 (B). This arrangement ensures similar stimulus density across different set sizes.

The 6 stimulus characters were each served as a target four times, twice paired with distractors of the same structure, and twice with distractors of different structures. The two different-structured distractors were pseudo-randomly chosen from the three characters in the different-structured group, with each character being used with approximately the same frequency over all the subjects. There was thus equal number of trials for both the same-structured and different-structured conditions. For example, if H1 was the target, there would be an equal number of target-distractor pairs in the same-structured condition (e.g., target-distractor pairs of H1-H2 and H1-H3) and in the different-structured condition (where the distractors were two randomly chosen vertical characters, say, H1-V1 and H1-V3). Six target characters each paired with 4 distractors made the total number of display types 24.

Within each display type, the three set sizes were each repeated 20 times, with an equal number of target-present and target-absent trials. For target-present trials, there would be one target presented among 0, 7, or 23 distractors, and for target-absent trials, no target but 1, 8, or 24 distractors were presented. The 60 trials for each display type were all presented within a single block. Three set sizes and two response types (YES for target-present trials and NO for target-absent trials) consisted of a complete set of 6 trials, presented in a random order and repeated 10 times. A random presentation order was used for the 24 blocks of display types. There were $24 \times 60 = 1440$ trials in total. Three factors (structure, set size, and presence) were all within-subjects designs.

Procedure. Except for the following difference, other details were the same as in the previous experiment. Before the presentation of each block of 60 trials, a target character was first shown on the screen, along with the sentences: "The above is the target. Keep it tightly in mind. Hit any key when ready." Twenty practice trials were run before the experiment, and characters used in the practice trials were different from those in the experiment.

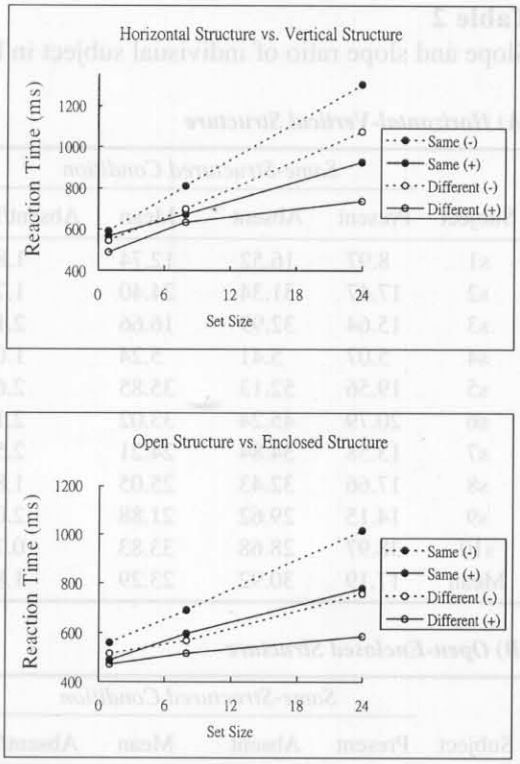


Figure 3. Mean correct reaction time as a function of the set size in Experiment 2. Closed circles = same structure, open circles = different structure, continuous line = target present, dashed line = target absent.

Results

Horizontal vs. Vertical Structure

The error rates were low under all conditions, with the overall error rate being 2.03%. The top panel of Figure 3 shows the average RTs across subjects for the four conditions to be compared: the target-present trials and target-absent trials in the

Table 2
Slope and slope ratio of indivisual subject in Experiment 2

(A) Horizontal-Vertical Structure

	Same-Structured Condition				*Different-Structured Condition*			
Subject	Present	Absent	Mean	Absent/Present	Present	Absent	Mean	Absent/Present
s1	8.97	16.52	12.74	1.84	5.38	12.15	8.76	2.26
s2	17.47	31.34	24.40	1.79	12.86	24.23	18.55	1.88
s3	15.64	32.99	16.66	2.11	16.13	28.49	22.31	1.77
s4	5.07	5.41	5.24	1.07	5.17	5.97	5.57	1.15
s5	19.56	52.13	35.85	2.66	15.02	43.50	29.26	2.90
s6	20.79	45.24	33.02	2.18	14.47	27.93	21.20	1.93
s7	13.58	34.84	24.21	2.57	9.05	29.87	19.46	3.30
s8	17.66	32.43	25.05	1.84	10.33	24.22	17.28	2.34
s9	14.15	29.62	21.88	2.09	7.52	13.68	10.60	1.82
s10	38.97	28.68	33.83	0.74	4.17	21.13	12.65	5.07
Mean	17.19	30.92	23.29	1.89	10.01	23.12	16.56	2.44

(B) Open-Enclosed Structure

	Same-Structured Condition				*Different-Structured Condition*			
Subject	Present	Absent	Mean	Absent/Present	Present	Absent	Mean	Absent/Present
s1	18.13	38.04	28.08	2.10	4.22	16.90	10.56	4.00
s2	14.07	22.27	18.17	1.58	4.16	5.54	4.85	1.33
s3	21.81	47.24	34.53	2.17	8.43	23.78	16.10	2.82
s4	10.58	11.53	11.05	1.09	2.73	2.44	2.59	0.89
s5	21.34	26.03	23.68	1.22	7.66	11.99	9.82	1.57
s6	13.79	26.30	20.04	1.91	2.97	8.66	5.82	2.92
s7	10.83	22.36	16.60	2.07	3.06	8.10	5.58	2.64
s8	8.88	18.92	13.90	2.13	3.74	8.25	6.00	2.20
Mean	14.93	26.59	20.76	1.78	4.62	10.71	7.67	2.30

same-structured condition as well as in the different-structured condition. Besides the group mean data of Figure 3, the values of the slopes derived from the best-fit linear function of the individual subjects were listed in the top panel of Table 2. Except for one subject, the percent variance that can be accounted for by linearity for each subject was more than 95%.

A three-way ANOVA shows that there were main effects on condition ($F(1, 9) = 57.32$, $p < .0001$), presence ($F(1, 9) = 23.79$, $p < .001$), and set size ($F(2, 18) = 64.19$, $p < .0001$). For set size only linear trend ($F(1, 18) = 128.22$) reached significant level, $p < .0001$. Two-way interactions of condition and set size ($F(2, 18) = 7.06$, $p < .01$), and presence and set size ($F(2, 18) = 21.56$, $p < .0001$) were significant. The simple main effects of set size at same-structured condition ($F(2, 36) = 68.91$, $p < .0001$) and at different-structured condition ($F(2, 36) = 35.14$, $p < .0001$) were significant, so as the simple main effects of set size at target-present trials ($F(2, 36) = 19.52$, $p < .0001$) and target-absent trials ($F(2, 36) = 85.30$, $p < .0001$). All linear trends of set size for the above four conditions were significant, $ps < .0001$.

An ANOVA for the search slopes derived from the linear regression of the RT means against set size for each subject shows the following. A significantly higher mean slope in the same-structured condition (23.29 ms/item) than in the different-structured condition (16.56 ms/item) was obtained, $F(1, 9) = 15.07$, $p < .005$. The mean slope for the target-absent trials (27.02 ms/item) was higher than that for the target-present trials (13.60 ms/item), $F(1, 9) = 23.24$, $p < .001$. No interaction effect of structure and presence was found. The mean absent/present ratio in the same-structured condition was 1.89, while it was 2.44 in the different-structured condition.

Open vs. Enclosed Structure

The error rates were low under all conditions, with the overall error rate being 1.45%. The bottom panel of Figure 3 shows the average RTs across subjects for the four critical conditions to be compared. The values of the slopes derived from the best-fit linear function of the individual subjects were listed in the bottom panel of Table 2. Except for one subject, the percent variance that can be accounted for by linearity for each subject was more than 95%.

A three-way ANOVA shows that there were main effects on condition ($F(1, 7) = 84.11$, $p < .0001$), presence ($F(1, 7) = 34.58$, $p < .001$), and set size ($F(2, 14) = 45.21$, $p < .0001$). For set size only linear trend reached significant level, $F(1, 14) = 90.32$, $p < .0001$. Two-way interactions of condition and presence ($F(2, 24) = 53.12$, $p < .0005$), condition and set size ($F(2, 14) = 88.26$, $p < .0001$), and presence and set size ($F(2, 14) = 14.86$, $p < .0005$) were all significant. The simple main effects of set size at the same-structured condition ($F(2, 28) = 86.92$, $p < .0001$) and at the different-structured condition ($F(2, 28) = 11.93$, $p < .0005$) were significant, so as the simple main effects of set size at target-present trials ($F(2, 28) = 16.37$, $p < .0001$) and target-absent trials ($F(2, 28) = 59.77$, $p < .0001$). All linear trends of set size for the above four conditions were significant, $ps < .0001$. A three-way interaction of condition, presence and set size was also significant, $F(2, 14) = 17.91$, $p = .0001$.

As for the search slopes calculated on the basis of individual slope estimates, the mean slope in the same-structured condition (20.76 ms/item) was higher than that in the different-structured condition (7.67 ms/item), $F(1, 7) = 93.61$, $p < .0001$. Also, the mean slope for the target-absent trials (18.65 ms/item) was higher than that for the target-present trials (9.78 ms/item), $F(1, 7) = 14.72$, $p < .01$. An interaction effect of structure and presence was also found, $F(1, 7) = 23.82$, $p < .005$. In the same-structured condition, target-absent trials have higher slope values than target-present trials, $F(1, 14) = 23.96$, $p < .0005$, the same was true in the different-structured condition, $F(1, 14) = 6.53$, $p < .05$. For both target-present and target-absent trials, significantly higher slopes were found in the same-structured condition than those in the different-structured condition. The mean slopes were 14.93 vs. 4.62 ms/item ($F(1, 14) = 49.25$, $p < .00001$) in the target-present trials, and 26.59 vs. 10.71 ms/item ($F(1, 14) = 116.89$, $p < .00001$) in the target-absent trials.

Discussion

Despite several different manipulations from the previous experiment were made in this experiment, the critical finding was repetitively obtained, indicating the robustness of this result. For both the H-V and the O-E structural dimensions, searching for a target among *different-structured* distractors was more efficient than among the *same-structured* distractors.

In Experiment 1, the subjects experienced more trials in the different-structured condition than that in the same-structured condition. Thus if familiarity effect developed within the experimental time frame can affect search efficiency, the faster search rate obtained from the different-structured condition may be due to its higher familiarity. When this confounding variable was controlled so that an equal number of same-structured and different-structured trials was conducted, a faster search rate was still found for the different-structured condition. This excludes the effect of familiarity formed within a short time frame as a determining factor for the different search rates found in these two conditions. It does not mean, however, that familiarity would not play any role if far more trials were run, or if the difference in the number of trials between these two conditions was enlarged. To have the search performance improved with practice, the effect of temporal familiarity would have to be strong enough to override the stable, well-learned structural distinctions.

The wider range of character frequency does not seem to be crucial for the faster search rate in the O-E dimension compared to that in the H-V dimension, either. When the character frequency was controlled within a narrow range and a different set of O-E structured characters were selected, the search slope was still very shallow for this particular structural dimension. The mean slope for the different-structured condition was 6.03 ms/item in Experiment 1, and it was 7.67 ms/item in Experiment 2, both would fall into the range of "quite efficient" search (Wolfe, 1996). These two slope values were very close, even when different sample characters and fonts were used. Also, these values were lower than those in the H-V dimension (which were 11.23 ms/item in Experiment 1 and 16.56 ms/item in Experiment 2), though all were consistent with the slopes found for the spatial configuration search in the literature (Wolfe, 1998). There may thus be an inherent difference between the search slopes of these two structural dimensions. We leave this comparison to Experiment 3 that was specifically designed to answer this question.

In this experiment, a standard visual search paradigm was used and a linear function was obtained. Although several changes have been made in this experiment, the major contribution to the change in the curve shapes from a power function to a linear one should go to the constant density display used in this experiment. Whether the target was known beforehand may not be crucial since even without a predesignated target as in Experiment 1 the same display type was presented repetitively within a single block. Soon the subject would be able to find out this regularity and searched for the presumed target. Moreover, similar curves as in Experiment 1 have been found when predesignated targets were searched (e.g., Takeuchi, 1997; Treisman & Gelade, 1980; Wolfe, 1992). The above two confounding variables, familiarity and frequency were both supposed to affect, if any, the within-dimension comparisons between the same-structured condition and the different-structured condition, while the change in the curve shape had occurred systematically across these two conditions. Character font should not have any effect on the curve shape, either, since for the H-V dimension the same font as in Experiment 1 was used yet different curve shapes were still observed.

Why then a power function was obtained with the constant extent display in Experiment 1 whereas a linear function was obtained with the constant density display here? For a display that had constant extent and varied item densities as in Experiment 1, as the number of items increased, the average distance between items decreased accordingly. If attention scans serially from one item to another at a fixed speed, then the scanning time between the items decreases as the set size is increased, causing the total scanning time to be shorter than what would be predicted by a strictly linear fashion.

Eye movements may have been involved here, too. No attempt was made in the experiments to control eye movements, and no assurance could be given of the steady fixation for displays lasted longer than 500 ms like ours. Although eye movements have been shown to be not the determining factor in visual searches (e.g., Klein & Farrell, 1989; Treisman & Gormican, 1988), the difference in the display patterns in Experiments 1 and 2 may have caused a difference in the eye scanning pattern. In Experiment 1 the entire display extent was kept constant, so that for a large set size, the best strategy would be to fixate the center of the entire display, which was near the center of the screen, and thus near the predesignated fixation pattern. For a smaller set size, the characters were presented at random locations in the field, inducing eye movements to bring the eyes to foveate on the geometrical center of the smaller displays. It may therefore take more time to move the eyes in a small set size than in a large one. When the density of the display items were kept constant as in Experiment 2, the best strategy was to fixate the center of the display. A more internal item-by-item scanning of attention was observed then.

Although the mechanism that causes the difference in the curve shapes between Experiments 1 and 2 (a power function vs. a linear function) is interesting in itself, we did not pursuit it further in this study since it is not the issue here. What we were interested in these two experiments was to explore the possibility that searching for a target among different-structured distractors would be more efficient than among same-structured distractors, and the results from both experiments confirmed this conjecture, which lay the ground for Experiment 3. Different-structured displays speeded up the search process compared to the same-structured ones, yet not all different-structured displays had the same effect (e.g., a faster search rate was found in O-E than in H-V), which may arise from the difference in the degrees of similarity between different structure types. As is argued by Duncan and Humphreys (1989), the differences in the RT × set size slopes can be largely explained by the similarity relationships between targets and distractors, when the distractors were homogeneous as used in this study. This point will be further examined using a within-subject design of structure pair in the next experiment.

Experiment 3

In our earlier reports (Yeh et al., 1997; 1999), in addition to the H-V and O-E structural dimensions obtained from MDS, five distinct clusters in the form of (H, L, V, P, E) were also consistently found from cluster analysis. Besides the similarity relationships of characters within each cluster, the similarity relationship between these clusters, namely, the superordinate or higher-order clusters, may also be inferred from the tree diagram of cluster analysis. Take the low-stroke count condition in Yeh et al. (1999) as an example. The five clusters can be further merged as [(H, L)], [(P, V), E]. Therefore the degree of similarity between H and V was higher than that between H and E, which may account for the slower search rate found for H-V than for O-E. In the two exploratory studies mentioned above, stroke count and occurrence frequency for the sample characters were purposely not controlled within too narrow of a range in order to cover more character types. In this experiment, we sought to find the similarity relationships between different structure types using the same visual search task, when stroke count and character frequency were well controlled. In this experiment, five structures in all possible combinations comprised 20 display types. We aimed at finding the differences in the search slopes, and take them as the index of the similarity relationship between different structure pairs.

Methods

Subjects. Twelve undergraduate students participated in this experiment to earn credits for their introductory psychology course. All were naive about the purpose of this experiment and had normal or corrected-to-normal vision.

Stimuli and Procedure. Five Chinese characters with the same stroke counts (8) and similar occurrence frequencies (see Appendix) were used as the stimuli. They were 狀 (zhuang4), 念 (nian4), 延 (yan2), 房 (fang2), 周 (zhou1), each representing the structure type H, V, L, P, and E, respectively. For the 5 stimulus characters, each with an equal chance to be a target, there were four types of distractors chosen from the other four characters. This made 20 blocks (5 × 4 display types) of 60 trials in total. Other details were the same as in Experiment 2.

Results

The overall error rate was 1.53%. An ANOVA shows main effects of structure ($F(19, 209) = 1.96$, $p < .05$), presence ($F(1, 11) = 181.47$, $p < .0001$), and set size ($F(2, 22) = 284.46$, $p < .0001$). The two-way interactions of structure and presence ($F(19, 209) = 2.65$, $p < .0005$), structure and set size ($F(38, 418) = 2.48$, $p < .0001$), and presence and set size ($F(2, 22) = 98.97$, $p < .0001$) were all significant, so as the three-way interaction of structure, presence and set size, $F(38, 418) = 1.55$, $p < .05$. For set size only a linear trend was significant, $F(1, 22) = 568.55$, $p < .0001$.

Since no significant search asymmetries were found when the same character pairs exchanged their roles as targets and distractors (e.g., H-V vs. V-H), data from two display types that were consisted of the same character pairs were collapsed. Therefore, the 20 display types were collapsed into 10 pairs to be compared. Figure 4 shows the average RTs across subjects for each pair. The search slopes derived from the best-fit linear functions of the group mean data were listed along with the figure legend of each pair (the number inside the parenthesis). For each subject, more than 98% of the variance was due to linearity. An ANOVA for the search slopes shows that the main effect of character pair was significant,

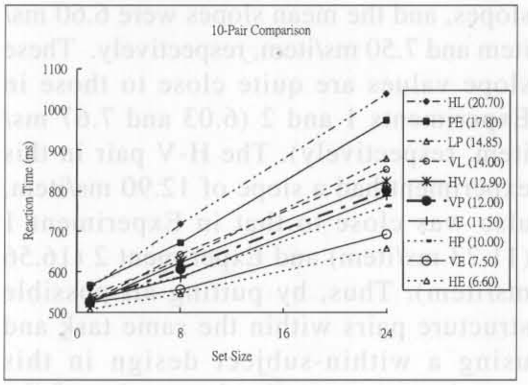


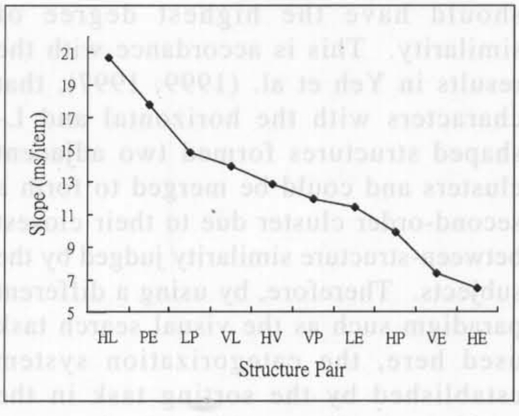
Figure 4. Mean correct reaction time as a function of the set size for the 10 structure pairs in Experiment 3. Note that these pairs were bi-directional, e.g., data from H (target)–V(distractor) and V(target)–H (distractor) were collapsed and represented by HV.

$F(9, 99) = 11.24, p < .0001$.

Figure 5 shows the gradient of the mean slopes obtained from the 10 character pairs (top panel) and the Tukey test for character pair (bottom panel). Take the most frequently used Horizontal characters (H) as an example to see the pairwise comparison of different structures. It can be seen that the highest search slope occurred for the H-L pair (20.7 ms/item), and the lowest for the H-E pair (6.6 ms/item). The mean slope of H-L is significantly different from that of H-P, H-V, and H-E, so as H-V from H-L and H-E, and H-E from H-L and H-V.

Discussion

By taking the Duncan and Humphreys (1989) model of visual search, we were able to measure the similarity relationship between different character structures. For a homogeneous background field as adopted here, the more similar the target-distractor pair, the higher the search slope should have the highest degree of similarity. This is accordance with the results in Yeh et al. (1999, 1997), that characters with the horizontal and L-shaped structures formed two adjacent clusters and could be merged to form a second-order cluster due to their closest between-structure similarity judged by the subjects. Therefore, by using a different paradigm such as the visual search task used here, the categorization system established by the sorting task in the previous studies could be further confirmed.



	HL	PE	LP	VL	HV	VP	LE	HP	VE	HE
HL				*	**	**	**	**	**	**
PE							*	**	**	**
LP									**	**
VL	*								*	**
HV	**									*
VP	**									
LE	**	*								
HP	**	**								
VE	**	**	**	*						
HE	**	**	**	**	*					

* : p < .05, ** : p < .01

Figure 5. Mean slopes for each structure pair (top panel) and the significance level of the differences between pairs (bottom panel) in Experiment 3.

it should be. It is then reasonable to do the "reverse engineering": to infer the degree of similarity between various target-distractor structures by comparing their search slopes. Furthermore, by using a visual search paradigm to find the inherent similarity relationships between various structure pairs, we would be able to provide one more piece of converging evidence for the structural categories of Chinese characters and their similarity relationships as first established by Yeh et al. (1997; 1999).

For example, in the continuum of search efficiency as depicted in the top panel of Figure 5, the H-L pair has the highest search slope, which means that among all the 10 structure pairs this pair should have the highest degree of similarity. This is accordance with the results in Yeh et al. (1999; 1997), that characters with the horizontal and L-shaped structures formed two adjacent clusters and could be merged to form a second-order cluster due to their closest between-structure similarity judged by the subjects. Therefore, by using a different paradigm such as the visual search task used here, the categorization system established by the sorting task in the previous studies could be further confirmed.

Due to the exploratory nature of the earlier two studies, the variance of the character frequencies and the character samples were chosen in a wide range. Even so, the five character clusters were repetitively and consistently found, which gave us enough confidence in this categorization scheme. Although the qualitative structure categories had been established quite firmly, what was less consistent across conditions was the quantitative similarity relationships between different structure categories. Many factors may have contributed to this subtle inconsistency, a different range of character frequency used and free viewing duration for sorting being two possibilities. By controlling the character frequencies of stimuli and using a reaction time measure, the results of Experiment 3 provided a continuum of similarity between structure categories unequivocally. The anchor point, the H-L pair, was consistently found to be the most similar pair in this study and the previous two studies, so as to ensure the cross-study validity.

A close scrutiny of Figure 5 helps clarify the result pattern of Experiments 1 and 2. In Figure 5, the H-E and the V-E pairs (jointly as the O-E pairs in Experiments 1 and 2) had the lowest search slopes, and the mean slopes were 6.60 ms/item and 7.50 ms/item, respectively. These slope values are quite close to those in Experiments 1 and 2 (6.03 and 7.67 ms/item, respectively). The H-V pair in this experiment had a slope of 12.90 ms/item, also was close to that in Experiment 1 (11.23 ms/item) and Experiment 2 (16.56 ms/item). Thus, by putting all possible structure pairs within the same task and using a within-subject design in this experiment, not only the results of the previous two experiments can be further verified, but also the differences between different structure pairs can be compared on better ground.

General Discussion

Three experiments were carried out in this study, and the results have demonstrated a substantial effect of the character structure on the subject's ability to discriminate between Chinese characters and the efficiency to search for a target character among distractors. For the purpose of demonstrating the effect of structure in visual search, we first chose target-distractor pairs that were located on the two sides of the H-V and O-E structural dimensions in the character space of Yeh et al. (1997; 1999). Although several different manipulations were made in Experiments 1 and 2, the same pattern of results was repetitively found that searching for a target character among homogeneous distracting characters was more efficient when the target was among distractors with different structures than with the same structure. It thus appears that character structures can be perceived and utilized in visual search, and the robustness of these results have lend the credence to further investigations. Hence, after establishing the structural effect in

Experiments 1 and 2, in Experiment 3 we further examined the five elaborated structure categories (H, L, P, V, E) obtained from cluster analysis in the earlier reports. The gradient in the search slopes was indeed found for various structure pairs as predicted.

In the visual search task as employed here, if we presented the target-distractor pairs with various degrees of similarity, thus in a continuum of search efficiency (Duncan & Humphreys, 1989), then this continuum should be observed by the differences in search slopes. In this aspect, the visual search task can be used as a diagnostic tool to reveal the degree of similarity between different character structures. This is the main purpose of Experiment 3, so we chose the characters with structures in various similarity relationships established by the sorting task in the previous two studies, and used them in the visual search task in this study. Since the observed slope differences between these structure pairs can be taken as indices of the similarity relationships between different structure pairs as argued above, we would be able to use a visual search paradigm to verify the similarity relationships between different character structures originally established by a sorting task. Also, from the general results of the previous studies, we should be able to predict the search efficiency of a particular character pair. For example, the L-shaped characters embedded in the horizontal distractors should be less discernible than in the vertical characters, since they are usually clustered with the former but not the latter (Yeh et al., 1997; 1999). The P-shaped characters may have a different pattern, however, being less separable from enclosed characters than from horizontal characters, according to the same source. This pattern of results was indeed found in Experiment 3.

Therefore, although the character classification system (Yeh et al., 1997; 1999) was established by using an unlimited duration, card-sorting task to allow high level cognitive processes to be involved, such a classification system undoubtedly still provides very useful information, yet this may not be obvious immediately. As argued by Yeh et al. (1999), classification is fundamentally important in every scientific field to lay the foundation for theory construction. This point is well illustrated in this study. The empirically found structural categories, the horizontal-vertical and open-enclosed structural dimensions from MDS were used in the first two experiments, and the five distinct structural types from cluster analysis were used in Experiment 3. Different search efficiencies for the same-structured and different-structured target-distractor pairs (Experiments 1 & 2) and for the 10 structural comparison pairs from the five structural categories (Experiment 3) were all found in the predicted direction. Although it may also be possible to find differences in search slopes using ANY randomly chosen characters, without a theoretical framework these differences would render meaningless. The classification system reported by Yeh et al. provides a model or framework as a basis for new predictions as offered above and confirmed by the results in this study.

It may be suspected that visual features other than character structures are the determining factors in the search efficiencies, as have been argued by several researchers (e.g., Duncan, 1983; Krueger, 1984; White, 1977) to oppose the category effect in visual search (Jonides & Gleitman, 1972; 1976; Gleitman & Jonides, 1976). The category effect refers to the phenomenon that finding a number among digits or a digit among numbers (between-category search) is parallel, while finding a number among numbers or a digit among digits (within-category search) is serial. Such effect has been assumed to reflect the partial processing in the between-category searches, since categorization may need fewer features to be checked than identification (Jonides & Gleitman, 1972; 1976; Gleitman & Jonides, 1976). Although the results in this study are similar to the findings of the category effect in that searching for different-category characters was more efficient than for within-category characters, we do not think that we have examined at the same level as that of the classical category effect in visual search. Differentiating numbers from digits involves semantic representations of both numbers and digits, whereas discriminating one structure from another may need only the perceptual-level representation. We chose as the stimuli characters that shared many of the same strokes, and thus the same features, such as orientation, curvature, etc., so generally the only difference between the targets and the distractors was the spatial arrangement of these features or strokes. A search of this sort was usually found to be inefficient, as indicated by the high slope values. Therefore, unlike the between-category parallel search that has been criticized as being the artifacts of detecting a particular feature (so as to turn it into a "parallel" or "easy" feature search), our results did not show such near-zero, feature-search like slopes. The open-enclosed structural dimension did show a much shallower slope, however, and it may be due to the percept of closure. Even so, we argue here that closure is also a characteristic of structure, being formed by the combination of features. Whether it is an "emergent feature" (e.g., Kovacs & Julesz, 1993; Treisman & Peterson, 1984; Julesz, 1981; Treisman & Gormican, 1988) is not crucial here. By definition, a character's configurational structure is formed by the spatial arrangement of strokes or radicals /parts. Differences between the target and the distractors that are not based on the "free floating" features would inevitably involve the spatial arrangements of those features, and the character stimuli used in this study are such cases. The spatial arrangement of strokes or parts is what the character structure we have been referring to.

Visual search paradigm has been widely used in the field of perception and attention in determining psychological primitives (Treisman, 1986; Wolfe, 1996). The RT × set size function, i.e., the slope value, is quite sensitive to the similarity relationship between the target and the distractors. We have used in our pilot study a discrimination task to examine the similarity between different characters. Four characters, three were the same and one was different, were presented in the four quadrants around a fixation plus sign. Subjects had to indicate which of the four quadrants contained a different character. Due to the reason that skilled readers as our subjects could rapidly process Chinese characters without any difficulty, by using only four characters in the display a ceiling effect was observed so that no sensible comparisons could be made. By increasing the display size and making it as one of the variables, the difficulty level was increased and the differences in the slopes of the RT × set size functions were more discernible. That was the main reason that we switched to the visual search paradigm. The sensitivity to the similarity/difference between target-distractor pairs and the robustness of the results constitute the two major advantages of the visual search paradigm.

There are also drawbacks in using visual search paradigm to study issues related to Chinese character processing, though. First, quite a number of trials for a certain target-distractor pairs have to be conducted as set size is an independent variable now, and several levels of this factor have to be manipulated to cover a reasonable range. Second, owing to the large number of trials needed for a certain target-distractor pair, only a restricted number of target-distractor pairs can be examined. In such a case, the sample characters selected have to be representative enough. In considering the numerous Chinese characters existed even for daily usage, to find a representative and unbiased sample set may not be an easy task. Third, although visual search is sensitive to the similarity/difference between target/distractor pairs, it cannot tell us how a Chinese character is processed. Note that we were quite aware of this and made no attempt in this study to infer any statement as such. We have used, instead, a primed naming task in a follow-up study to examine more directly whether character structure affects character recognition.

To sum up, by using a visual search task in this study we have provided another piece of converging evidence concerning the classification scheme of character structures and their similarity relationships established in the earlier two studies. Our earlier reports helped to lay the foundation of the classification system using a sorting task without time constraints, and this study further confirms it with better controls in RT measures. Moreover, a new approach of similarity estimates by taking the search slopes between different target-distractor pairs has been developed.

Implications of such results are as follows. The similarity indices obtained from the search slopes of the 10 pairs resulting from the five structure categories can be helpful in the selection of the character stimuli for the cognitive studies of Chinese. In experiments using Chinese characters as experimental stimuli it is often needed to control for the visual similarities of the characters, which is usually done by the researchers' intuition or by following the unspecified tradition in the literature. Generally, characters sharing the same strokes or parts were treated as similar. Though it is intuitively straightforward, it has not been verified. Most importantly, in this way two characters can only be qualitatively specified as either similar or dissimilar, quantitative measurement between the similarities of characters is not possible. A continuum in similarity of character stuctures such as provided here will not only provide a better control of similarity for selecting appropriate characters as experimental stimuli, but will also allow quantitative predictions to make. For example, besides the positive or negative effect of priming, the quantitative measures of priming will also be possible if the similarity in structures between the prime and the target determine the priming effect. This work is in progress now.

There are also applications of this similarity scale. Evaluation of the visibility and readability of the visual displays and computer processing of Chinese characters are such examples. Effective data compression is important in capacity-limited systems as humans and computers. Though in the field of artificial intelligence, mechanisms of human information processing can be totally ignored and yet a workable and successful system still be found, knowing how humans do will usually help in designing a system as efficient as that of human's. Therefore, realizing humans do perceive structural information in Chinese characters and obtaining the gradient of the processing efficiency between different structure pairs will help to conserve this important structural information and compress others.

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Appendix. Stimulus materials for this study

Experiment 1 & 2

(A) Horizontal vs. Vertical

Structure	Character	Frequency
Horizontal	怕	2068
Horizontal	拒	2192
Horizontal	板	2750
Vertical	享	1578
Vertical	宗	3043
Vertical	念	3835

(B) Open vs. Enclosed

Experiment 1: constant extent

Structure	Character	Frequency
Open	夜	3731
Open	卦	98
Open	念	3835
Enclosed	固	1678
Enclosed	周	4105
Enclosed	函	1791

Experiment 2: constant density

Structure	Character	Frequency
Open	析	2017
Open	妻	1881
Open	俊	2033
Enclosed	固	1678
Enclosed	周	4105
Enclosed	函	1791

Experiment 3

Structure	Character	Frequency
Horizontal	狀	4024
Vertical	念	3835
L-shaped	延	3915
P-shaped	房	5007
Enclosed	周	4105

Frequency: Occurrence frequency taken from the Corpus-Based Frequency Count of Characters in Jounral Chinese (Academic Sinica, Taipei, 1993).

中文字形結構的偵測：以視覺搜尋斜率值作爲結構間相似性的指標

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本研究以三個視覺搜尋實驗來檢驗中文字形結構對搜尋效率的影響。在實驗一中受試者的作業是在一群相同的中文字（干擾字）中儘快判斷是否有一個不同的字（目標字）。每次嘗試所呈現的刺激總數不定，隨機呈現在5×5的矩陣方格內，而由反應時間與刺激總數的函數圖形可推知內在的處理速率。干擾字與目標字可能共享相同的結構（同構組），也可能爲不同的結構（異構組）。所檢驗的字形結構爲葉素玲等人（1997；1999）以字形分類作業經多向度量尺法（MDS）所得的兩種結構向度（水平／垂直、開放／包圍）。實驗二改將刺激以固定密度的方式呈現，受試者的作業是搜尋預先指定的目標字，同構組與異構組的嘗試次數相等，並將目標字與干擾字的字頻控制在更接近的範圍。即使這些改變，兩個實驗的結果皆顯示異構組比同構組有較快的搜尋速率。實驗三將葉素玲等人（1999）經群聚分析所得的五種結構類別兩兩配對呈現，結果顯示當目標字與干擾字二者的結構愈相似，所得的搜尋斜率值愈大，因此可藉由搜尋斜率值作爲字形結構之間相似性的指標。文中並討論本研究結果的意涵及其應用。

關鍵詞：中文字形、結構、相似性、視覺搜尋