The Effect of Visual Search Strategy on Alphanumeric Category Effect

Tsubasa ISHIDA

Graduate School of Information Sciences, Tohoku University,
Katahira 2-1-1, Aoba-ku, Sendai 980-8577, Japan
(E-mail: tbs-i@cpsy.is.tohoku.ac.jp)

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"Alphanumeric category effect" refers to the finding that letters and digits are identified more efficiently when they were presented among items from the opposite category (a between-category condition, BC) than among items from the same category (a within-category condition, WC). Two experiments in this article revealed that the category effect occurred when BC and WC condition were divided into blocks but did not occur when these were not divided. This means that the category effect is due to strategy of the subjects rather than to category relation between target and distractor.

KEYWORDS: alphanumeric category effect, visual search task, character stimuli

1 Introduction

Most of earlier researches on visual search employed relatively simple stimuli, e.g., line, circle, color and simple conjunction of them, and most of theories (Treisman & Gelade, 1980, etc.) about this area are based on the results of those previous researches. On the other hand, there are several studies employing relatively complex stimuli, e.g., characters, and those theories are unable to explain results of the studies employing relatively complex ones. "Alphanumeric category effect" is one of the effects that is yet to be clarified.

The alphanumeric category effect occurs in the visual search task employing two categories (e.g., letter and digit) of characters as stimuli (Cardosi, 1986). This effect refers to the finding that letters and digits are identified more efficiently when they were presented among items from the opposite category (a between-category condition, BC) than among items from the same category (a within-category condition, WC). When digits are searched they are searched faster among letters than among digits, and vice versa. A very small search rate was observed for BC search in several researches (Egeth, Atkinson, Gilmore & Marcus, 1973; Egeth, Jonides & Wall, 1972; Jonides & Gleitman, 1972), which suggests that the characters are searched in parallel manner.

The category effect cannot be explained by the theories about the visual search mentioned above. Character stimuli are complex visual objects, therefore it is presumed that they are processed later stage in visual information processing. Moreover, since characters have meanings they are processed not only by visual information analysis process but also by semantical one considered to be more later stage, we can predict that they should be searched in serial. Treisman & Gelade (1980) confirmed that character stimuli were searched serially in their Experiment 4.

Contrary to these predictions and observations, the category effect is the phenomenon that character stimuli are searched in parallel. The theories mentioned above, e.g., Treisman & Gelade (1980) etc., are required further modification in order to explain the category effect.

Furthermore, the effect is inconsistent with the dominant notion about coding and memory system of characters. Although the effect suggests that character categorization is faster than character name discrimination, character category is hierarchically subentry of character name (Can you categorize a character you don't know the name?) and more time is required to access to character category than to character name. Actually Posner (1970) observed that character naming is faster than category matching.

Ishida (1996) investigated the category effect with LED characters which were physically similar each other and reported no category effect. From this result, he concluded that the category effect is caused by physical features rather than category information.

However, it has been pointed out that experimental design may be one of the factors that affect occurrence of the category effect with the following reason. The effect appeared when BC and WC condition were divided into blocks while did not appeared when those were not divided (Gleitman & Jonides, 1978). In the experiment of Ishida (1996), BC and WC were not divided into blocks. It might be caused by experimental design that the category effect was not observed.

Gleitman & Jonides (1978) employed a go/no-go task and observed RT only for the target present condition. However, comparison of search rate between the target present and absent condition was necessary to discriminate self-terminated and exhausted search. This discrimination would be also an evidence for serial search. Since the task and the experimental design employed by Gleitman & Jonides cannot bring us sufficient data to
discriminate such two search manners, this study aims to re-examine their results with observing RT for both the target present and absent condition. The present experiment examines whether the search rate when BC and WC are divided into blocks (Experiment 1) would be different from the rate when they are not divided (Experiment 2). If the category effect is caused by the only physical properties of stimuli, the subjects’ performance on Experiment 1 and 2 would not be different. Otherwise, if the category effect is affected by blocking WC/BC, the performance would be different.

2 Experiment 1

WC and BC were divided into two blocks. Letters were used as the targets in one block and digits were used as targets in the other. Distractors were letters. That is, letter target block corresponded to WC and digit target block corresponded to BC. Thus the subject could know category relation between the target and the distractor prior to each trial. In this design the target should be searched in parallel for BC block and in serial for WC (Gleitman & Jonides, 1978).

2.1 Method

Subjects The subjects were 9 graduate and undergraduate students, 6 were female and 3 were male.

Apparatus The experiment was controlled by PC/AT compatible personal computer. Stimuli were presented on 17 inch computer display at a 75-Hz refresh rate. RT was measured with timer board (Interface Corp IBX-6101) and recorded at 0.1 ms timing resolution. Two keys were connected to measure subjects’ responses. Each subject’s head held on a chinrest located 1 m from the display.

Stimuli Characters appeared at 12 locations on an imaginary circle corresponding to the 12 clock positions (1:30, 2:30, . . . , and 12:30). Diameter of the imaginary circle was about 0.4 degree of visual angle. The center of the imaginary circle corresponded to that of the display and fixation point (See Fig. 1 for an example of stimulus presentation).

Target characters were "4" and "5" for digits; "A" and "S" for letters. They were chosen for the reason that "4" was similar to "A", and "5" was similar to "S". Distractor characters were "C", "D", "E", "F", "H", "K", "N", "V" and "Y". Fontface of stimuli characters was TrueType font “Gothic-BBB Medium fixed-pitch” attached with Apple KANJJITalk7.

Procedure Subjects participated in a session for about one hour. The session consisted of two blocks. On one block targets were letters (e.g., "A" and "S") and on the other they were digits (e.g., "4" and "5"). In both blocks, target was absent for half of the trials and was present for the other half. The order of the two blocks was counterbalanced across subjects. Display size was set at 2, 4 or 6.

At the beginning of each block, the subjects were informed of the two target characters but not informed of the category of distractors. They received 204 trials after 60 practice trials for each block. Each trial began with an appearance of a fixation point (+ mark) for 2 s followed by stimuli characters for 200 ms. The subjects were instructed to identify whether the target character was present or not on the display and to respond as quickly and correctly as possible by pressing one of the two keys. 'Present' response was responded by pressing the key assigned to right index finger and 'absent' was done by pressing the key assigned to left index finger. Following subject's key response, correctness of the response was informed by presenting a ‘+’ or ‘-’ mark on the center of the display.

Fig. 1 An example of stimulus presentation at 6 display size, BC and the target present condition.
2.2 Results

Reaction Time  RT obtained from error trial, and outlier were omitted. The definition of outlier is identical to that of boxplots (Bohrnstedt & Knoke, 1988). Means of RT medians for each subject are plotted in Fig. 2. Table 1 also shows the means of estimated slopes and intercepts from regression analysis for each subject.

RT data were analyzed by ANCOVA with GLM procedure of SAS. Display size was treated as the covariance as well as the factor. These procedures can test difference of slopes and intercepts of regression line for each condition. The other factors were treated as the fixed factor. The main effect of display size ($F(1, 8) = 12.34, MS_e = 8102.23, p = .008$) and target presence ($F(1, 8) = 25.21, MS_e = 540.02, p = .001$), the interaction of category relation × display size ($F(1, 8) = 55.25, MS_e = 1072.96, p < .001$) and that of category relation × target presence × display size ($F(1, 8) = 7.49, MS_e = 191.25, p = .026$) were significant.

Further analysis of simple main effect was performed on the category relation factor with individual error term. For BC, the simple main effects of target presence and display size were significant, but the simple interaction of them was not significant. Since the $F$ value for the simple interaction effect was less than 1, effect size of the effect might be null. On the other hand, for WC simple main effect of target presence, display size and the simple interaction of them were significant. As a consequence of the significant interaction, the search rate varied between the target present and absent condition; the search rate for the target present condition was smaller than that for absent. Analysis of simple main simple effect was also performed on the target presence for WC. The simple main effect of display size was significant for both the target present and absent condition.

Thus, it was found that the search rate was not zero statistically and not different between the target present and absent condition for BC. While they were different for WC; the search rate for the target present condition was smaller than that for the target absent.

Error rate  Table 2 shows means of error rates at each condition.

The arcsine transformed error rates were analyzed in the same fashion as RT. The main effect of display size ($F(1, 8) = 57.62, MS_e = 0.0117, p < .001$), interaction effect of category relation × target presence ($F(1, 8)$

![Fig. 2](image)

Means of the RT medians for each subject as a function of display size for Experiment 1. (BC: Between Category condition, WC: Within Category condition.)

<table>
<thead>
<tr>
<th>Category relation</th>
<th>BC</th>
<th>WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>12.54</td>
<td>17.54</td>
</tr>
<tr>
<td>Absent</td>
<td>14.27</td>
<td>35.41</td>
</tr>
<tr>
<td>Intercept (ms)</td>
<td>469.80</td>
<td>492.44</td>
</tr>
<tr>
<td>Target</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>553.70</td>
<td>543.90</td>
</tr>
</tbody>
</table>

Table 1. Means of slopes and intercepts obtained by regression analysis for Experiment 1. (BC: Between Category condition, WC: Within Category condition.)
Table 2. Means of percent error rates for Experiment 1. (BC: Between Category condition, WC: Within Category condition.)

<table>
<thead>
<tr>
<th>Display Size</th>
<th>Category relation</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BC</td>
<td>Present</td>
<td>Absent</td>
<td>WC</td>
<td>Present</td>
</tr>
<tr>
<td>2</td>
<td>4.4</td>
<td>4.1</td>
<td></td>
<td>14.0</td>
<td>1.7</td>
</tr>
<tr>
<td>4</td>
<td>6.6</td>
<td>7.1</td>
<td></td>
<td>13.2</td>
<td>7.0</td>
</tr>
<tr>
<td>6</td>
<td>13.1</td>
<td>9.5</td>
<td></td>
<td>21.2</td>
<td>21.4</td>
</tr>
</tbody>
</table>

= 14.70, MS = 0.0149, \( p = .005 \), that of category relation \( \times \) display size \( (F(1, 8) = 6.36, MS_e = 0.0152, p = .04) \) and that of category relation \( \times \) target presence \( \times \) display size \( (F(1, 8) = 9.43, MS_e = 0.0176, p = .02) \) were significant. Further analysis of simple main effect was performed on the category relation factor. For BC none of the effects were significant and for WC simple main effect of the target presence and display size were marginally significant.

The data suggest no reason to alter conclusions discussed above.

2.3 Discussion

In Experiment 1, the search rates were almost identical for the target present and absent condition in BC, while in WC they were smaller for the target present than for absent.

The characteristic observed for WC is consistent with that of serial search with the assumption that self-terminated search was conducted. That is, the search rate for the target present condition is almost half of that for the target absent. Contrary to this finding, characteristics observed for BC are consistent with that of parallel search. The search rate for target present is identical to that for target absent.

It can be pointed out, however, that the search rate for BC is too large to claim parallel search. According to Wang, Cavanagh & Green (1994), recent visual search researchers claimed that the search rate criterion for discriminating parallel search from serial search is from 6 to 10 ms/item. Moreover, Treisman & Gelade (1980, Experiment 4) conducted an experiment which employed visual search task with letters, and reported 4.9 ms/item as a search rate for the target present condition. In this experiment the search rate was 12.54 and 14.27 ms/item for the target present and absent condition respectively, which are larger than the criterion and the result.

However the claims of Wang et al. and other recent researches are especially based on the experiment employing relatively simple stimuli (e.g. line, circles, conjunction of them, etc.) so that these claims cannot be applied simply to this experiment which employed relatively complex stimuli (e.g. characters). Furthermore the experiment of Treisman & Gelade employed a task to search only one target (e.g., "T"), while this study employed a task to search two kinds of targets (e.g., "A" and "S", or "4" and "5"), hence it might be easier to search the targets in their experiment than in ours. Therefore higher search rate might be inevitable for this experiment. Accordingly, this results suggest that the targets are searched in serial for WC and in parallel for BC, when the BC/WC were divided into separate blocks.

3 Experiment 2

In Experiment 2, BC and WC were not divided into blocks, while they were divided into 2 blocks in Experiment 1. That is, targets were letters and digits for both blocks so that subjects could not know the category relation between target and distractor prior to each trial. In this design the targets should be searched in serial for both BC and WC (Gleitman & Jonides, 1978).

3.1 Method

Subjects The subjects were 8 graduate and undergraduate students, 4 were female and 4 were male.

Apparatus The apparatus used was the same as that described for Experiment 1.

Stimuli The stimuli used were the same as that described for Experiment 1.

Procedure The procedure used in Experiment 2 was the same as that described for Experiment 1, except the following points. On one block, target was "4" for 1/3 of the trials, "S" for other 1/3 or absent for the other 1/3; on the other target was "5" for 1/3 of the trials, "A" for other 1/3 or absent for the other 1/3. The order of these two blocks was counterbalanced across subjects. One block contained 54 practices and 180 trials.

3.2 Results

Reaction Time The RT data were analyzed in the same fashion as Experiment 1. Fig. 3 shows the RT as a func-
Fig. 3  Means of RT medians for each subject as a function of display size for each condition for Experiment 2. (BC: Between Category condition, WC: Within Category condition, TA: Target Absent condition.)

Table 3. Means of slope and intercept obtained by regression analysis for Experiment 2. (BC: Between Category condition, WC: Within Category condition, TA: Target Absent condition.)

<table>
<thead>
<tr>
<th>Category relation</th>
<th>BC</th>
<th>WC</th>
<th>TA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (ms/item)</td>
<td>12.54</td>
<td>12.52</td>
<td>39.78</td>
</tr>
<tr>
<td>Intercept (ms)</td>
<td>464.79</td>
<td>523.96</td>
<td>548.08</td>
</tr>
</tbody>
</table>

The results of ANCOVA were as follows. The main effect of category relation ($F(2, 7) = 10.30$, $MS_{e} = 486.26$, $p = .002$), display size ($F(1, 7) = 7.28$, $MS_{e} = 13907.43$, $p = .03$) and the interaction of them ($F(2, 7) = 8.71$, $MS_{e} = 1686.96$, $p = .004$) were significant. They were also significant with Geisser-Greenhouse correction (Keppel, 1991, 352–353, 465).

The interaction of category relation and display size was also analyzed by analysis of interaction comparisons (Keppel, 1991, 236–237) in which an interaction transformed into multiple interactions. That is, the interaction of category relation (BC, WC and TA) × display size was analyzed by being transformed into three interactions, e.g., the interaction of category relation (BC and TA) × display size, the interaction of category relation (WC and TA) × display size and the interaction of category relation (BC and WC) × display size. On these comparisons, the interactions of category relation (BC and TA) × display size and category relation (WC and TA) × display size were significant. On the other hand, the interaction of category relation (BC and WC) × display size was not significant and the effect might be null because the $F$ value was less than 1. The analysis of simple main effect was performed on the category relation factor and the simple main effect of display size were significant on all conditions.

Thus, it was found that the search rate was statistically not zero in all conditions and the search rates did not vary between BC and WC, while they varied between TA and BC/WC.

**Error rate** Table 4 shows means of error rates at each condition.

The error rate were also analyzed in the same fashion as RT and only the main effect of display size ($F(1, 7) = 44.31$, $MS_{e} = 0.0091$, $p < .001$) was significant. The data suggest no reason to alter conclusions discussed above.

### 3.3 Discussion

The search rates were not different between BC and WC, while they were different in Experiment 1. The search rate for TA was significantly larger than that for the two target present conditions, e.g., BC and WC. This characteristic was the same as that of serial search, therefore we can conclude that serial search was consistently conducted in Experiment 2.
Table 4. Means of percent error rates for Experiment 2. (BC: Between Category condition, WC: Within Category condition, TA: Target Absent condition.)

<table>
<thead>
<tr>
<th>Display Size</th>
<th>Category relation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BC</td>
</tr>
<tr>
<td>2</td>
<td>1.3</td>
</tr>
<tr>
<td>4</td>
<td>2.1</td>
</tr>
<tr>
<td>6</td>
<td>3.9</td>
</tr>
</tbody>
</table>

4 General Discussion

When BC and WC were divided into blocks and the subjects could know the category relation between targets and distractors of the trial to come, the subjects searched the targets in serial under WC, while they searched them in parallel under BC. These characteristics suggest that the search was more efficient under BC than under WC, which are identical to the category effect (Cardosi, 1986). On the contrary, since the subjects searched the target in serial both in BC and WC when these conditions were mixed in a block and they could not know the category relation, the category effect did not occur. These results suggest the possibility that absence of the category effect reported in Ishida (1996) is caused by the experimental design he employed rather than physical similarity of stimuli.

Our findings were consistent with those of Gleitman & Jonides (1978) with some exceptions. They employed a go/no-go task in which subjects were instructed to press a key when a target was present, so that only the results for the target present condition are comparable between the results of their study and of ours. In their Experiment 1, BC and WC were divided into blocks and the observed search rate was 12.2 ms/item and 43.6 ms/item for BC and WC respectively (estimated from their Fig. 1), while in this study it was 12.54 ms/item and 17.54 ms/item respectively. For BC search rates were almost identical between their study and ours, whereas for WC they were not identical. In their experiment the search rate difference between BC and WC was large enough to obtain significance, but in this experiment no significant difference was observed ($F(1, 8) = 2.40, MSe = 913.23, p = .160$).

One possibility causing such inconsistency between Gleitman & Jonides (1978) and our study is that different characters were used as stimuli. "D", "K", "P", "3", "4" and "9" were employed as targets in their experiment, whereas "A", "S", "4" and "5" were employed in our experiment. Duncan (1983) employed the targets ("A", "Z", "2", "4") which were more similar to those of our study than those of Gleitman & Jonides. His study showed closer result (23 ms/item for BC and 29 ms/item for WC) to ours. This fact suggests an evidence for the possibility.

The fact that search rate was affected by a choice of target characters also suggest a possibility that the the effect of physical feature difference is greater than that of the category effect. Although this problem is pointed out in earlier studies (Cardosi, 1986; White, 1977), this study is not designed to examine such possibility and we discuss no further about it here.

Another possibility of the difference is in the procedure of the stimulus presentation. Gleitman & Jonides (1978) presented a pattern masking after each stimulus, however our study did not. The absence of masking might increase the time to process visual information and facilitate the performance of our subjects. However, this cannot explain the observation for BC search that the search rates were almost identical to the both studies, so it may not be the case.

Next, we will consider why the experimental design affects the occurrence of the category effect. Gleitman & Jonides (1978) explained the effect of experimental design with "partial processing hypothesis" proposed by Gleitman & Jonides (1976). In their hypothesis, categorization requires less complete information than discrimination and requires less matching time for each presented stimulus. In the experiment of Gleitman & Jonides (1978), subjects searched the target more efficiently under the condition in which BC/WC were divided into blocks than under the condition in which they were mixed, because the subjects could choose these alternative strategies, e.g., the strategy processing partial (less complete) information and the strategy processing full (complete) information under the former condition, while they could not choose under the later.

However, the hypothesis does not predict whether search was conducted in serial or parallel, and it cannot explain the result of this study that parallel search was conducted under BC while serial search was done under WC. Gleitman & Jonides (1978) did not refer to the parallel/serial problem, because they observed RT for only target present condition, which was insufficient to discriminate serial search from parallel one.

However, under the assumption that the partial information required for categorization is some kind of primitive features which should be processed in parallel, the hypothesis can explain the results of this study. Under BC in which targets are able to be discriminated from distractors based on categorization, subjects searched the targets in parallel using partial information, e.g., primitive features. On the other hand, under WC in which
they are unable to be done, they searched the targets serially with conservative strategy, e.g., with that using full information.

The results of Posner's (1970) study, however, were inconsistent with the hypothesis. Posner conducted an experiment using a task to match two characters which were same or different in the character names or categories (vowel or consonant, letter or digit). His experiment resulted in slower RT for category matching than for name matching. This implied that information processing for category matching would be slower than that for the character name discrimination, which is apparently inconsistent with the partial processing hypothesis. However, Posner's experiment employed only two letters and we can consider that his subjects could obtain the prediction or priming after processing one character and before processing another. Moreover, we can assume that the degree of the prediction or priming was larger for the name matching task than for the category matching. This assumption is based on the spreading-activation theory by Collins & Loftus (1975). Most of nodes have fewer links for name association (e.g., node "A" has only one link for "a") than for category association (e.g., node "A" has links for "B" to "Z"). Therefore, the name association activates fewer nodes than when category association does. Under further assumption that activation spreading to each node may be stronger in inversely proportional to the number of linked nodes, the spreading activation is stronger for name one than for category one. In the visual search task employed by both Gleitman & Jonides and our study, any prediction or priming was unavailable because the distractors were other characters than the targets for WC and they were in the another category for BC. Although categorization may be faster than the naming, the degree of it might be suppressed by the facilitation of naming based on such a prediction or priming in Posner's experiment.

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REFERENCES