Processing of repeated letters in search and matching tasks

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Several published experiments have used a variant of the matching or "same"- "different" paradigm in which the subject indicates whether or not all of the items in a visual array are the same. Contrary to the results of most paradigms in which subjects process multiple items, reaction time (RT) in this matching task is independent of the number of items in the display (N). One possible explanation of this independence holds that subjects respond to some overall property of the display, such as its general symmetry, and not to the individual items. I tested this hypothesis with a visual search task in which subjects searched a circular display of $N = 2, 4$, or 6 letters for a specified target letter under three stimulus conditions. In the varied condition, the nontarget letters were all different from each other. In the repeated condition, the nontargets were repetitions of the same letter, but a single discrepant letter was always present in the display. The uniform condition also used repeated nontargets, but the negative (target-absent) displays contained N repetitions of a single nontarget item. I found that RT increased at a rate of 27 msec/item for the varied condition, but at only 13 and 8 msec/item in the repeated and uniform conditions, respectively. The slopes in the latter conditions were significantly lower than the slope for the varied condition, and they also differed significantly from each other. Hence, there was some advantage attributable to properties of the overall patterns associated with positive and negative responses, suggesting that at least some responses were based on these properties. There was a much larger advantage, however, attributable to the use of repeated nontargets, regardless of whether the overall patterns differed. This latter observation implies that the flat RT functions observed in matching studies must be interpreted primarily in terms of responses to individual items rather than to the pattern as a whole.

In 1969, Donderi and Zelnicker described an experiment in which subjects were required to indicate whether or not all of the geometric forms included in a brief visual display were the same. The number of forms varied from 2 to 14 , and the forms were arranged haphazardly within a field of constant size. On a "same" trial, all of the forms were identical, whereas for a "different" trial, one of the forms differed from the rest (e.g., eight circles and one triangle). The basic result of the study was that mean reaction time (RT) was independent of the number of forms in the display. This result is remarkable because virtually every other binary-classification task involving multiple items has yielded increasing RT functions over the number of items to be processed (cf. Nickerson, 1972). Hence, it may be of value to find out why the RT functions are flat in this particular paradigm.

The result of Donderi and Zelnicker (1969) was replicated by Donderi and Case (1970), who also found that the "different" response was faster when there were three discrepant forms in the display (e.g., a circle, a semicircle, and a square among five triangles) than when there was only a single discrepant form (a circle among seven triangles).

Egeth, Jonides, and Wall (1972, Experiment 1) obtained flat RT functions using repetitions of the characters C and 4 to compose their displays, with two, four, or six characters appearing in a circular pattern. Connor (1972, Experiment 1) also obtained flat RT functions using $3, 6$, and 12 distinctive letters distributed uniformly across a constant linear span.

In short, the observation of flat RT functions in this paradigm has been well replicated. It should be noted that each of the studies cited used forms or characters which were visually distinct from one another. By contrast, Connor (1972, Experiment 3) observed small (5 - to 10 -msec) slopes in the RT functions when visually confusable letters were used, and Egeth, Jonides, and Wall (Note 1) obtained a substantial slope (about 20 msec) when the similar letters E and F were used to generate the displays. Hence, the observation of flat RT functions depends upon the use of visually distinctive items. Aside from this constraint, the flat function has been obtained with a variety of procedures and stimulus materials.

Why, then, does this paradigm yield flat RT functions when other search and matching tasks consistently yield increasing functions? Connor (1972) and Egeth et al. (1972) interpreted the flat functions as evidence for parallel (simultaneous) processing of the display items; the idea is that, because the subject processes all the items at once, it doesn't matter how many there are. By contrast, Donderi and Case (1970)

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		Response	
		"yes"	"no"
Condition	Varied	K F H * T C R	K F H * D C R
	Repeated	F F T * F F F	F F S * F F F
	Uniform	H H H * H H T	H H H * H H H

Figure 1. Sample stimuli for positive and negative responses for a target letter T under three stimulus conditions.

and Donderi and Zelnicker (1969) suggested that repetitions of items are automatically encoded in terms of the same mental representation, and that RT is a function only of the number of internal codes activated by the display.

Although these two positions differ, they are similar in that they both assume that the subject responds to the individual items in the display. No one, to my knowledge, has considered the possibility that the subject processes the display as a whole. The "same" and "different" displays certainly differ as overall patterns, since "same" displays have a roughly uniform distribution of visual features throughout the pattern and "different" displays contain a discrepant set of features in a randomly selected region. Fox (1975) has recently demonstrated that subjects use the overall symmetry of a visual display as a time-saving diagnostic in the matching of letter pairs. His results suggest that subjects might use a property like overall symmetry to make their responses in the matching task under consideration here.

Regardless of the particular property or properties involved, however, the general proposition I am introducing is that the subject in this task responds to the display as a pattern and not to its individual elements. Given this interpretation, it is not surprising that RT is independent of the number of items included in the pattern.

Fortunately, there is a straightforward way of determining whether subjects are basing their responses on the patterns or the items in this task. The essential question is whether the flat RT functions are obtained when the patterns associated with the two responses do not differ in their general characteristics. This question can be answered by using variations on the visual search paradigm introduced by Atkinson, Holmgren, and Juola (1969). In this paradigm, the subject is given a single target

letter followed by a display containing a variable number (N) of test, or "probe" (Nickerson, 1972), letters. If the target letter is included in the probe display, the subject presses a button to indicate "yes"; if it is not, the subject presses a button to indicate "no."

Consider the following three stimulus conditions based on this paradigm. The three conditions are exemplified in Figure 1, where the target is presumed to be the letter T and the number of probe letters is assumed to be six. The varied condition represents the sort of stimuli used by Atkinson et al. (1969), with N different letters appearing in each display. In the repeated condition, there is always one unique letter, which may or may not be the target, and N - 1 repetitions of a nontarget letter. In the uniform condition, the display contains a unique letter only on positive trials; on negative trials, the same nontarget letter appears in all N positions of the display.

The varied condition ought, of course, to replicate the findings of Atkinson et al. (1969); namely, linearly increasing RT functions with slopes on the order of 25 msec. By contrast, the uniform condition ought to reproduce the flat RT functions of the matching studies reviewed above, since the stimuli are composed in the same way. The only real difference between the uniform condition of the search task and the matching studies is that in the former case the identity of the discrepant letter, if present, is specified in advance. Egeth et al. (1972, Experiment 2) explored this condition and found that, although a significant slope was obtained for the "yes" response, the mean slope across the two responses was only 3 msec, which is very nearly flat.

The crucial condition shown in Figure 1 is the repeated condition. This condition uses repeated nontargets, but the stimulus patterns associated with the two responses are structured in the same way. If the flat RT functions observed in matching studies are attributable to the processing of individual items, as assumed in the published interpretations reviewed above, then the functions ought to be flat in the repeated condition. If, however, the flat functions are attributable to responses based on overall differences between positive and negative patterns, then the functions ought to be increasing in the repeated condition.

To make the test implied by this discussion, I ran a visual-search experiment with the three conditions shown in Figure 1, with each subject serving in a single condition.

METHOD

Subjects

Thirty-seven students from an introductory psychology course served for 1 h as part of a course requirement. One subject was eliminated from the data analysis for exceeding a predetermined

criterion on the permissible number of errors, as described below. This left 36 subjects, 12 in each of three conditions.

Apparatus

The experiment was controlled and data were recorded by a Nova 2/10 computer manufactured by Data General Corporation. A Lexiscope 2000 alphanumeric terminal (Lexicon, Inc.) was used to present instructions, display stimuli, and provide feedback to the subject. Responses were registered by pressing either of two labeled keys located in the outer corners of the Lexiscope keyboard.

Stimuli

The letters used in the experiment were the consonants C, D, F, H, J, K, L, R, S, and T. I chose these particular consonants for maximum distinguishability in the character set produced by the display unit. The characters were formed within a 5 by 7 dot matrix, which measured 2.4 mm wide x 5.7 mm high. The probe displays contained six fixed positions in a roughly circular pattern, as shown in Figure 1. This pattern was 16 mm wide x 22 mm high. Viewing distance was not controlled, but was approximately 50 cm. Hence, the visual angle for the height of a single character was just over $\frac{1}{2}$ deg, and the entire probe pattern was contained in about 2.5 deg of visual angle.

Procedure

The general paradigm was the visual-search task described above. Each trial of the experiment consisted of a 750-msec presentation of the target letter, a 500-msec interstimulus interval, a 150-msec presentation of the probe pattern, a 1,350-msec interval during which the screen was blank, and a 2,250-msec intertrial interval during which an asterisk was displayed on the screen in the place where the next target would appear. The computer accepted responses during the 1,500-msec interval measured from the onset of the probe pattern to the return of the asterisk. If the subject failed to respond during this interval, the query "no response?" was briefly displayed and the next trial initiated. Failures to respond were treated as errors in feedback to the subject, but were deleted from the data analysis reported below.

The circular probe pattern was centered on the spot where the asterisk and the target letter appeared. For each positive trial, the computer program randomly selected the location where the target item would appear within the probe display. The arrangement of the remaining letters was also determined randomly, but with the restriction that each display contain two letters which were opposite each other on the circle, so that the visual angle could be held roughly constant. The identity of the target letter was determined randomly for each trial, and the identities of the nontargets in the probe display were also chosen randomly within the constraints of the three experimental conditions described below.

There were six different types of trial in the experiment: Probe display sizes of $N = 2, 4,$ and 6 were each used with both positive ("yes") and negative ("no") trials. Trials were grouped in blocks of 24, with each of the six types of trial appearing four times in a block. The order in which the types appeared was determined randomly by the program for each block. At the end of each block, the subject was shown a table recording the number of errors and the mean RT for the blocks he or she had completed. This table was presented for 30 sec, and then the next block was begun.

An experimental session consisted of 4 practice blocks of 12 trials each followed by 12 experimental blocks of 24 trials each. Each practice block contained a random subset of the stimuli comprising a full experimental block. The data from the practice blocks were not included in the analyses reported below.

Instructions for the task appeared on the Lexiscope screen, with the subject indicating his comprehension of each panel of instructions by pressing one of the response keys. The instructions included a general description of the task, a slow-motion example and description of a typical trial, and instructions as to which key to press for "yes" (target present) and "no" (target absent) responses. Half the subjects in each condition used their favored hands to

make a "yes" response and half used their nonfavored hands. The instructions also described the nature of the feedback and directed the subject to respond as quickly as possible without making more than two errors in any one block. Subjects who made more than nine errors in any one block or who made an average of three or more errors in all the blocks (i.e., 36 or more errors in the entire session) were excluded from the subsequent data analysis. As noted above, one subject was excluded for this reason, and his data were replaced by running another subject in that condition.

Conditions

The three conditions of the experiment, the varied noise, repeated noise, and uniform conditions, are exemplified in Figure 1. In the varied condition, N different letters appeared in the probe display. In the repeated condition, there was one unique letter, which was the target letter on positive trials, and $N - 1$ occurrences of a nontarget letter, for a total of two different letters in the display. In the uniform condition, the positive-trial displays were the same as those for the repeated condition, whereas the negative-trial displays consisted of N occurrences of a single nontarget letter.

Each subject participated in only one condition. The three conditions differed only in the composition of the probe displays.

RESULTS

The mean RTs for correct responses are shown in Figure 2, and the mean proportions of errors are shown in Figure 3. Each point in these figures is based on 576 observations. There were only 16 failures to respond within the 1,500-msec response interval out of 10,368 observations, and these failures were excluded from consideration in the computation of the error rates.

The two statistics, mean RT and proportion of errors, were each subjected to a four-way analysis of variance with three within-subjects factors and one between-subjects factor. The within-subjects factors were N , which was separated into linear and quadratic components through the use of planned comparisons; response type (positive and negative); and practice. This last factor had four levels, which were obtained by collapsing data across Experimental Blocks 1 to 3, 4 to 6, 7 to 9, and 10 to 12. The between-subjects factor was condition. Pilot work had suggested that the data from the repeated condition would appear more like that of the uniform condition than that of the varied condition, so I used the following planned comparisons for the condition factor: first, repeated vs. uniform, and second, varied vs. repeated and uniform combined. I used an arcsine transformation for the error proportions.

The analysis of RT data revealed a significant effect of N in the linear component, $F(1,66) = 242.14$, $p < .001$, but not in the quadratic, $F(1,66) < 1$. There were also significant effects of response, $F(1,33) = 123.44$, $p < .001$, and of practice, $F(3,99) = 94.23$, $p < .001$. However, there was no simple effect of condition in either the first comparison, $F(1,33) < 1$, or the second, $F(1,33) = 3.08$, $p > .05$, although the second comparison (varied vs. the other

Figure 2. Mean reaction times for correct responses.

Figure 3. Mean proportions of errors.

two conditions) approached significance. The interaction between the linear component of N and the condition factor was significant for both the first comparison, $F(1,66) = 4.75$, $p < .05$, and the second comparison, $F(1,66) = 56.70$, $p < .001$. There was also a significant interaction between response type and the condition factor for both the first comparison, $F(1,33) = 11.65$, $p < .01$, and the second, $F(1,33) = 6.29$, $p < .05$. Finally, there was a significant triple interaction among the linear component of N , response type, and the comparison between the varied condition and the other two conditions, $F(1,66) = 12.00$, $p < .01$.

Combining the results of this analysis with Figure 2 yields the following set of conclusions. First, the RT functions were linearly increasing over N , with positive responses being faster than negative responses by a nearly constant amount; there was a small, but significant, divergence of positive and negative RTs over N in the varied condition relative to the repeated and uniform conditions. Second, the slopes of these linear functions were much greater for the varied condition than for the other two conditions, and the slopes were reliably greater for the repeated

condition than for the uniform condition. Third, the advantage of positive responses over negative responses was greatly reduced in the uniform condition relative to the other two conditions. Finally, subjects became faster overall with practice, but the pattern of results was not affected by degree of practice.

Averaging RTs across positive and negative responses, the slopes of the best fitting straight lines to the data are 27.13, 13.38, and 7.84 msec/item for the varied, repeated, and uniform conditions, respectively. To determine which of these slopes were significant, I did a supplemental analysis for each condition. The influence of N in the linear component was significant in all three conditions: $F(1,11) = 89.05$, 64.02, and 28.67 for the varied, repeated, and uniform conditions, respectively, with $p < .001$ in each case. The quadratic component was not significant for any condition.

The analysis of error proportions revealed an effect of N in the linear component, $F(1,66) = 9.11$, $p < .01$, but not in the quadratic component, $F(1,66) < 1$. There was also an effect of response type, $F(1,33) = 7.69$, $p < .01$, but not of practice, $F(3,99) < 1$, or condition, $F(2,33) < 1$. There was a significant interaction between the linear component of N and response type, $F(1,66) = 14.48$, $p < .001$, and between practice and response type, $F(3,99) = 3.62$, $p < .05$. There were two triple interactions among N , response, and condition. The first was among the linear component of N , response, and the comparison between the repeated and varied conditions, $F(1,66) = 5.24$, $p < .05$. The second was among the quadratic component of N , response, and the comparison between the varied condition and the other two conditions, $F(1,66) = 8.16$, $p < .01$.

Combining this analysis with Figure 3 and a partition of the data by blocks of trials yields the following conclusions: Subjects initially made about as many false alarms as misses, but with practice the false alarms decreased in frequency and the misses increased. This shift left the overall error rate roughly constant over practice, but resulted in a net preponderance of misses in the errors. Also, the proportion of misses increased with N while the proportion of false alarms did not. The first triple interaction reflects the fact that the difference in slopes between misses and false alarms was much greater in the repeated condition than in the uniform condition. The second triple interaction appears because the functions for the misses and false alarms diverge at $N = 4$ for the varied condition, whereas this divergence doesn't occur until $N = 6$ for the other two conditions. The overall proportion of errors was .034.

DISCUSSION

The fact that misses increased with N but false

alarms did not is in accord with a guessing model I have applied to a multiletter matching task (Taylor, Note 2). Essentially, the model asserts that each time a subject completes the processing of an item there is a constant probability that he or she will make the negative response immediately rather than wait until all of the items have been completed. This guessing strategy reduces mean RT but produces occasional misses, and the frequency of these misses increases with N. The interaction with practice suggests that subjects did not begin the session with this strategy, but adopted it only after some experience with the task.

The triple interactions in the error data don't fit with any processing scheme I am aware of, so I will not venture to interpret them. On the whole, the error rates were comfortably low, and they did not covary with the comparisons of interest in the RT measure, so the effects in RT may be interpreted with confidence.

As expected, the results of the varied condition replicated the findings of Atkinson et al. (1969). In particular, the slope estimate of 27.13 msec for this condition is quite close to the value of 25 msec reported in the Atkinson et al. (1969) study. Contrary to expectations, however, the RT function was not flat in the uniform condition. Although the slope of 7.84 msec is small relative to the slope of the varied condition, it is still significantly different from zero. Any interpretation of this slope is bound to be speculative, but it is worth noting that the slope is right in the middle of the range of values obtained by Connor (1972) for confusable letters using the matching procedure. This observation tempts me to suggest that the slope may be attributable to confusability of the characters. Although I selected the characters for their apparent distinctiveness, they were formed by just 10 or 12 luminous dots, and some pairs of characters differed from each other by only a few dots.

Regardless of the source of the small slope in the uniform condition, the results of this condition can still serve as a standard of comparison for the repeated condition. The critical question for the thesis of this study is whether the repeated condition yielded slopes like those of the varied condition or like those of the uniform condition. The strict answer to this question is that neither result was obtained; the slope for the repeated condition was much lower than the slope for the varied condition, but it was still slightly higher than the slope for the uniform condition. Hence, there was a substantial advantage of having repeated items for nontargets, but there was also some advantage in having the positive and negative displays differ as patterns as well. On the whole, the slopes of the repeated condition were much more similar to those of the uniform condition than to those of the varied condition. This conclusion is based on

inspection of Figure 2, comparison of the slope estimates for the three conditions, comparison of the relative magnitudes of the F ratios for the N by Condition interactions (56.70 vs. 4.75), and the observation that the repeated and uniform conditions both showed some convergence of the positive and negative RT functions while the varied condition showed divergence of these functions.

This study, then, permits two major conclusions. First, when repeated items are used as nontargets in a visual search task, there is a small, but significant, advantage to having the positive and negative displays differ as overall patterns. Hence, subjects' decisions in this task are probably based partly on the appearance of these patterns. For example, it might be that asymmetry serves as a diagnostic (Fox, 1975) only when the choice and placement of the items makes it particularly obvious.

The second conclusion is that there is a major advantage in using repeated items as nontargets rather than varied items, regardless of the overall patterns of the displays. This result indicates that subjects in this task do process the individual items. The finding must be generalized to the matching paradigm with some caution, first because a small difference in procedure is involved and secondly because the RT functions in the uniform condition were not quite flat. However, the result does provide a fairly strong case for interpreting the flat RT functions observed in the matching studies in terms of the processing of individual items.

The question remains as to just how subjects process these items. As Egeth et al. (1972) have pointed out, the range of multi-item-processing models that can account for flat RT functions is really quite limited (see also Taylor, in press). Although the data of the present study do not address this question, I would like to suggest that the phenomenon under consideration may actually be more perceptual in nature than has been considered in previous accounts. Specifically, it may be that the repetition of the nontarget item causes the target to "stand out" perceptually, so that the target is rapidly localized and it alone receives further processing. The work of Beck (1967, 1972) indicates that this perceptual location effect exists, and that it is most powerful when the items in the display differ in the angles of their constituent features, as would a triangle among circles (Donderi & Zelnicker, 1969) or the characters C and 4 (Egeth et al., 1972). A compelling aspect of this account is that the same factor, visual distinctiveness, accounts both for the presence of the flat functions with distinct items and for their absence with confusable items. Further research efforts might profitably be directed toward confirming the operation of perceptual localization in the matching paradigm, as well as toward a clarification of the way in which this localization is accomplished.

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