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ABSTRACT

The effects of types of both memorized items and probes (digit, word, and dot pattern), using Sternberg's character-recognition procedure, were studied. Reaction time (RT) was a linear function of the set size of memorized items consistent with a serial search model. Response type (positive or negative) affected the encoding time (intercept of RT function) or probes only, and was explained by a rechecking operation. Finally, probe types had effects on both search rate (slope) and encoding time, but types of memorized items affected neither. These results were discussed in terms of the encoded information and its relations to search operation. (Author)

Number encoding and matching in short-term memory

Leonard Katz and David A. Wicklund

In a simple match task, Posner and Mitchell (1967) presented pairs of letters, capital or small, to which S responded "same" or "different" as quickly as possible. They found that physical matches (both letters either capital or small) were about 80 msec. faster than name matches when the stimuli were presented simultaneously. But the advantage of physical matches disappeared when the stimuli were separated by 2 sec. or more (Posner & Keele, 1967; Posner, Boies, Eichelman & Taylor, 1969). From these results the nature of storage codes which follow after the visual presentation was inferred; visual and name components of a visual stimulus overlap within memory. If the second stimulus is visually identical to the first, memorized, stimulus, Ss may respond "same" by using physical identity alone without going to the name level. If the visual representation is no longer active, S must then match at the name level. The efficiency of this visual code for matches decline to that of the same code in about 2 sec.

Another approach to memory codes is provided by the character-recognition procedure introduced by Sternberg (1966, 1967). Sternberg (1967) manipulated both the set size of memorized items and the type of the probe, intact or degraded, and found that the effects of the degraded probe were mainly on the intercept of a linear function between reaction time (RT) and a set size of memorized items. He concluded that those theories of character recognition which argue that the stimulus probe is subjected to some form of analysis or refinement before being matched with stored representations best accounted for his results.

The present experiment studied the nature of the memory code for cardinal number for three different visual representationsof number: digit, word, and dot pattern. A combination of the Posner and Mitchell (1967) and Sternberg (1966) procedures was used to provide information not only about the degree of visual information utilized but also about how that information was used in the memory scanning process. On each trial, a memory set of one, two or four items was presented in one of the three visual representations. The probe stimulus which followed was also one of the three visual forms and was varied factorially with the form and size of the memory set.

It was expected that the latency of a match would be a linear function of memory set size, and that scanning would be exhaustive; these results have typically been obtained in high-speed memory scans for digits and figures (e.g., Sternberg, 1967; Briggs & Blaha, 1969). This linear function implies that the encoding process of probes occurs prior to, and is independent from, the memory search process. Associated with other data (Posner, et al, 1969) two kinds of prediction can be derived from this implication. On the one hand, if matches are based primarily on a visual code, slopes (search rates) in the condition that probes are physically identical to memory set item should be faster than those in the conditions that probes are not. This is suggested by the advantage of visual matches to name matches in Posner et al experiments (1967, 1969). Meanwhile, the difference in encoding times of visual and name codes can also be inferred. On the other hand, if matches are based primarily on a name code, then differences in the slopes would not be expected to occur as a function of physical similarity between probes and memory set items. Above all, in both cases difference in intercept might occur as a function of the type of the visual probe which occurred because of different times necessary to transform each type of probe to a certain memory code as suggested by Mackworth (1963).

Method

Subjects. The Ss were twelve Chinese male graduate students at the University of Connecticut. They were paid $4.50 for their participation. One additional S was discarded because of his high error rate and slow RT.

Stimuli. A varied memory set procedure was followed, i.e., the items to be remembered were changed from trial to trial. Memory set size (MS) was varied in blocks from one to four items. For each MS, all MS items on a given trial were presented in one of three visual forms (MF, memory form): (1) digit, e.g., 7,2;(2) word, e.g., seven, two; or (3) dot pattern, where the pattern consisted of the appropriate number of dots for each item in the pattern displayed on common playing cards.

Each MF in each MS was presented with one of three visual forms for the memory probe. The probe was a single item and the three probe forms (PF) were identical to the memory forms.

On each trial, a given probe was either positive or negative, i.e., (R, response type) was either a member of the memory set for that trial or it was not. Each combination of MF, PF and R was repeated five times in a block of 90 trials. Each MS contained four blocks for 90 trials each, except for MS = 3, used for practice, which contained only one block. In the total of 360 trials for each MS, each of 10 cardinal numbers appeared twice as a probe. Equal repetitions of each cardinal number also occurred within each memory set.

Thirty two-number memory sets and 90 four-number memory sets were repeated twelve and four times, respectively, of which half were positive R and half were negative. Sequences of stimuli in each block were random under the constraint that there be no more than three successive correct R trials.

Procedures. Ss ran a given MS in a given experimental day in 4 blocks and were arranged according to Latin Square design. Memory sets were presented on a Stowe memory drum in a simple comparison task which required Ss to respond "positive" or "negative" depending on whether the probe was or was not contained in the memory set. For "positive" response, it could be the same physical display or the same name, and "negative" response, otherwise. Before the beginning of the experiment, Ss were shown the whole set of stimuli, instructed in the equivalence among stimuli and asked to memorize them.

The presentation time of the memory set was 4 sec. in all cases, presumably long enough for each S to easily read all items. And memory set was immediately followed by the probe. Memory set changed over trials and the intertrial interval was about 2 sec.

RT and R in each trial were recorded. Ss were instructed to respond as accurate and as fast as possible. No information about their results was given them, but "Very good: Try harder to respond as fast and as accurately as possible next time" were repeatedly said to them after finishing each block. There was ten minutes of rest between blocks.

Results and Discussion

Mean latencies were computed based on all correct responses in each of 18 conditions (i.e., 3 levels of PF, 3 levels of MF and 2 levels of R) for each of 4 blocks of 90 trials in each of 3 levels of MS for each S. The error rate was below 5% in 41 of 54 subject-blocks and never exceeded 9.2%. An analysis of variance was performed on the mean latencies. All significant effects and their estimated population variances (Myers, 1966) are presented in Table 1. The variance components were estimated in order to obtain a precise idea of the relative sizes of effects. All main effects, except MF, were significant, $p < .001$ and all first-order interactions, except Block x R and MS x R, were significant, $p < .01$.

Insert Table 1 about here

The largest effect in Table 1 is due to MS, whose estimated variance is at least 3.7 times greater than the other treatments. The next two largest factors are PF and R. Memory form, MF, was not significant. The effect of Blocks was significant, as were several interactions involving blocks. However, these effects were small relative to the significant main effects discussed. A treatment of the larger effects will be presented first.

Figure 1 presents mean latencies as a function of MS, PF, and R. The lines are least-squares linear fits. Inspection of Figure 1, taken together with the results of the analysis of variance, indicates increases in RT with increases in MS. The digit form of the probe is faster than the word and dot pattern. Also, negative response are slower than positive responses. The absence of a MS x R effect suggests that scanning was exhaustive. A small MS x PF effectexists, and appears to be due to the slightly steeper slope of the figure probes compared with the digit and word probes. A small PF x R effect appears to be due to a smaller difference between positive and negative latencies for word probes than for digit or figure probes.

Insert Figure 1 about here

The lack of any strong effects involving MF suggests that Ss transform all three memory set forms into some common form for storage. While such a result is not typically found when presentation intervals under 2 seconds are used (eg., Posner et al, 1969), the interval in the present study (four seconds) was evidently long enough for Ss to encode the MF stimuli into common form (probable the stimulus "name"); Ss only slightly utilized the visual information in the different memory set forms.

The similar slopes and differences in intercept (about 70 msec.) between digit probes and word probes suggests that Ss performed, in sequence, a probe transformation and a memory scan. The data suggest that a digit probe is transformed to common form faster than a word probe. The size of the difference in intercept between words and digits suggest that not much of the difference can be attributed to differential read-in time.

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Table 1

Main effects, significant interactions from analysis of variance and their estimated components of variance ($\hat{\theta}^2$).

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Source	Mean Squares	DF_1/df_2	F	$\hat{\theta}^2$
M. size (MS)	8.445	2/22	37.3***	.00951
P type (P)	2.256	2/22	99.2***	.00258
Response type (R)	1.398	1/11	64.2***	.00105
Block (B)	.243	3/33	11.8***	.00034
T type (T)	.024	2/22	1.7	
P x MS	.073	4/44	7.1***	.00022
B x MS	.069	6/66	5.1***	.00026
M x MS	.016	4/44	4.4**	.00004
P x M	.044	4/44	3.5**	.00013
P x B	.012	6/66	3.3**	.00004
M x B	.025	6/66	5.3***	.00009
P x M x B	.012	12/132	3.0**	.00011
P x M x B x MS	.018	24/264	4.4***	.00060
P x R	.096	2/22	8.1**	.00019
M x R	.029	2/22	5.7*	.00006
P x M x R	.015	4/44	3.4*	.00007
P x B x R	.022	6/66	5.3***	.00016
P x B x R x M	.018	12/132	4.7***	.00040
P x B x R x M x MS	.015	24/264	3.4***	.00089

*** $P < .001$

** $P < .005$

* $P < .025$

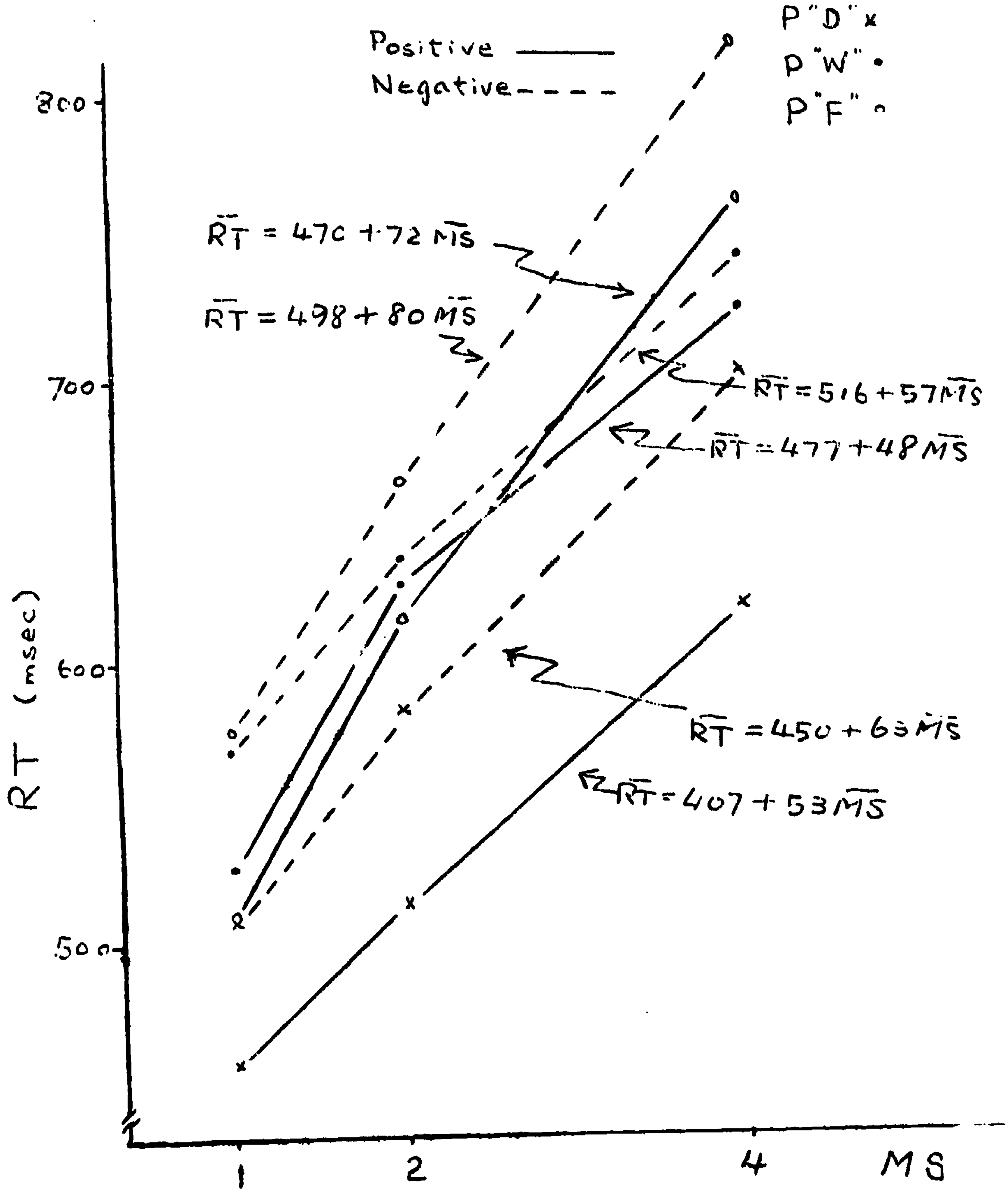

Fig. 1 RT AS A FUNCTION OF MS, P AND R