Parallel processing in item recognition*

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It is shown that in Sternberg's item recognition task Ss need not make a judgment of the absolute size or color of the test item before comparing it with memory. However, Ss do use size or color information, when possible, to reduce long reaction times for large memory loads. The results suggest that Ss are able to scan memory for form in parallel with testing for gross stimulus features, like size or color. This finding has important implications for sequential two-stage theories of attention.

Several current theories of pattern recognition postulate multiple stages in the classification of visual stimuli. An important feature of these theories is the additivity, or successiveness, of the hypothesized stages. For example, Neisser (1967) has proposed two sequential stages of processing; the first stage, preattentive processing, operates on easily discriminable physical features of stimuli and can serve to direct attention and control simple discriminative responses. The second stage, focal attentive processing, typically involves extensive contact with memory, and is required for stimulus identification and control of more complex responses. Similarly, Smith (1968) and Sternberg (1967) have argued for two successive processing stages prior to response selection in the stimulus classification task: a stimulus encoding stage, in which the physical stimulus is translated into some internal representation, and a memory comparison stage, in which this representation is compared against similar representations stored in memory.

Whereas evidence for Sternberg's additive model comes primarily from his studies of item recognition (Sternberg, 1966, 1967), Neisser's sequential two-stage theory is derived mainly from several experimental studies of visual search. These studies have generally shown that nontargets which can easily be discriminated from targets can be rejected with little or no increase in overall search time. For example, Green and Anderson (1956) and Smith (1962) found that nontargets that could be discriminated from targets on the basis of color increased search times only slightly when they were added to the visual displays. However, search times did increase linearly with the addition of same-color nontargets. Similarly,

Williams (1966) found that informing Ss of the color of the target to be searched for in a large field of different-colored objects decreased both overall search time and the number of fixations needed to find the target. In addition, Neisser (1963) found that the time to find a target letter in a large array of letters decreases as the noise letters become more dissimilar to the target. Direct measurements of eye movements during visual search further support these findings (Gould & Dill, 1969); distinctive nontargets could be rejected peripherally without ever bringing the fovea to bear. All these findings suggest that distinctive nontargets can be rejected at an early stage of processing, presumably without focal analysis.

While these results do appear to support a sequential theory, they do not rule out an alternative hypothesis—that of parallel operation of preattentive and focal processes. There is, in fact, some evidence which raises doubt about the assumption that objects are processed focally only after they have been selected preattentively. Beller (1968) had Ss search through circular displays of two- and three-digit numbers for targets whose size was specified beforehand. Noise items were either the same size as the target (relevant nontargets) or different (irrelevant nontargets). Applying Neisser's model to this task, Beller fit the following equation to his data:

$$T_s = A + B \cdot n_r + C \cdot n_i \quad (1)$$

Search time (T_s) is predicted to be a linear function of the number of relevant nontargets (n_r) and the number of irrelevant nontargets (n_i). This model assumes that preattentive and focal stages are sequentially organized, that their times are additive, and that irrelevant items are processed preattentively at a fast rate (C msec/item) and relevant items are processed focally at a relatively slow rate (B msec/item). For the most part, the data were fit quite well by this equation. The model, however, broke

down in the following way. Beller found that varying the difficulty of the size discrimination did have an effect on the time to reject irrelevant nontargets (preattentive processing time, C) as expected, but it had no concomitant effect on the time to reject relevant nontargets (focal attentive processing time, B). But if the stages are sequential, focal attentive processing time must include preattentive processing time as well. This result led Beller to suggest that perhaps preattentive and focal attentive processes overlap in time.

Thus, it is possible to entertain an alternative hypothesis based on parallel operation of preattentive and focal processes. For Beller's task, it is possible that central comparison of each successive test object against the target(s) in memory is begun, after some initial encoding, before the decision on the basis of physical size is made. However, if the time needed for the memory comparison always exceeds that for the physical discrimination, then this assumption leads to processing times indistinguishable from those of the sequential hypothesis. Thus, in the absence of systematic variations of the duration of the memory comparison, we cannot choose between these alternative interpretations.

The purpose of the present experiments is to test directly the hypothesis that item recognition and physical discrimination of a single test item can occur in parallel. In the present task, some nontargets could be rejected on the basis of a size or color discrimination, while others could be rejected only after a search through memory. To insure a test between parallel and sequential models, both the time required by the physical discrimination and the time required to search memory were systematically varied. This was accomplished by a modification of Sternberg's item recognition task (Sternberg, 1969). In the typical item recognition task, S memorizes a short list of items and then judges whether or not a single test item is present in the list. However, in the present experiments, Ss could also respond to some test items on the basis of a single physical discrimination. The control conditions involving item recognition alone and size discrimination alone were also conducted. The strong prediction of the parallel hypothesis is that item recognition and size discrimination should take the same amount of time, regardless of whether they occur together in the experimental conditions or separately in the control conditions.

The first experiment involved a memory search of from one to four

*This research was supported by Public Health Service Research Grant MH-07722 from the National Institute of Mental Health. The authors are grateful to Richard Young for his comments on an earlier draft of the paper and to Lawrence Macupa for his assistance in gathering data.

Fig. 1. Latency and error rate for standard and small test letters as a function of memory load for each condition of Experiment 1. Standard error rates are shown separately for positive and negative letters. Regression lines and equations are shown for the standard RTs.

items in conjunction with a size discrimination. Nontarget items were either the same size as the target, or were smaller; the difficulty of the size discrimination was systematically varied. In addition, the usual item recognition task, in which size was not relevant, was employed as a control condition. Experiment 2 served as a control condition for size discrimination; Ss made discriminative responses only to the size of the test letters. Experiment 3 involved an additional test of the hypothesis where the physical discrimination could be made on the basis of color.

EXPERIMENT 1

Method

Subjects. Forty introductory

psychology students served as Ss in partial fulfillment of a course requirement. They were assigned to the four conditions in order of appearance so as to achieve 10 Ss per group. Five Ss were replaced for failure to meet a predetermined error criterion (10%).

Apparatus. A two-field Polymetric tachistoscope was used to present the stimuli. The S indicated his response by pressing one of two microswitches. Latencies were measured to the nearest .01 sec by a Standard Electric clock and recorded by E.

Stimuli. The memory sets and test letters were drawn from the 26 letters of the alphabet. They were stenciled in black ink on white 5 x 8 in. cards

using Pickett "Modern Bold (Vertical) Lettering Guides."

A standard block of 96 memory sets and test letters was constructed in which each letter subtended 36 min of visual angle. The memory sets varied in length from one to four different, randomly selected letters, with 24 sets of each length. Positive and negative test letters were equally probable for each of the memory set sizes. The location of positive test letters was varied equally over all serial positions, while negative test letters were chosen randomly from letters not in the memory set.

Three additional blocks of 48 memory sets and test letters—12 for each memory set size—were independently constructed (negative-small). For these blocks, test letters were always chosen randomly from letters not in the memory set. The letters in the memory sets each subtended 36 min of visual angle, while test letters subtended 30, 24, or 18 min for the three blocks, respectively.

Procedure. There were four groups of Ss. Three experimental conditions were determined by varying the ratio of the height of the standard to the negative-small test letters—36:30, 36:24, or 36:18 min, respectively. In these conditions, Ss were instructed that small test letters would not be present in the memory sets and were encouraged to respond negatively as soon as they detected a small test letter. In addition, a control condition was run using the memory sets and test letters of the 36:30-min experimental condition, but with no size instructions. None of the control Ss reported noticing any differences in the heights of the test letters.

Each S served for one session in which he received 144 trials composed of 96 lists from the standard block and 48 lists from one of the negative-small blocks. Thus, positive, negative, and negative-small test letters each occurred with probability 1/3. The order of the 144 trials was random.

On each trial, the memory set was displayed until S pushed a ready button. After a 1-sec interval, the test letter appeared and remained visible until S responded. The task was to decide whether the test letter was present in the memory set and to register the decision by pressing one of two response keys (positive or negative). The hands assigned to the response keys were counterbalanced across Ss within each condition. After each response, S was told his latency if he was correct, or that he had made an error, otherwise. The Ss were instructed initially to respond rapidly while making as few errors as possible. The 144 trials in each session took roughly 30 min and were preceded by

Table 1
Difference Between Standard and Negative-Small RTs (Msec) as a Function of Memory Load: Experiment 1

Condition	Memory Set Size			
	1	2	3	4
Control	-3	-12	23	33*
36:30	-6	-4	7	32*
36:24	2	10	18	33*
36:18	0	1	47†	83†

* $p < .05$, † $p < .01$

24 practice trials.

Results

For each S, arithmetic means over the correct reaction times (RTs) for each memory set size were obtained for the standard and negative-small test letters. No S made errors on more than 10% of the total trials; overall error rate was 4.46%. Figure 1 shows mean RT for standard and negative-small test letters as a function of memory load, for each of the four conditions. Least-squares fits and parameters are shown for the standard test letters.

Standard test letters. The results shown in Fig. 1 suggest that RT is a linear function of memory load in each condition. Trend analysis supports this impression: The overall effect of linear memory load accounted for 99.0% of the variance of memory load, while the quadratic component was not significant, $F(1,36) = 1.15$, $p > .2$. There is also an indication that the standard test letters were processed equivalently in all four conditions, since there was no effect of conditions, $F(3,36) = 1.50$, $p > .2$, nor was there a difference in linear trend among the conditions, $F(3,36) < 1$.

A more powerful test of the equivalence of processing in the four conditions was made by performing multiple t tests between both the slopes and intercepts of the least-squares fits for each pair of conditions. None of the differences between the slopes or intercepts was found to be significant (all $ps > .1$). Moreover, the least-squares fit to the RTs averaged over the four conditions yields a slope and intercept of 44 and 431 msec, respectively, in excellent agreement with the values reported in previous item recognition studies (e.g., Sternberg, 1969). Thus, it seems

reasonable to conclude that the main feature of the processes typically employed in item recognition, the serial comparison of the test item against the items in the memory set at a rate of about 40 msec per comparison, is not disrupted by the additional task of discriminating the height of the test letter.¹

Negative-small test letters. That the Ss were, in fact, discriminating the height of the test letter is suggested by Fig. 1 and the results of the following analyses. For the negative-small test letters, the linear component of memory load was significant, accounting for 89.9% of the variance of memory load. However, for these stimuli, the quadratic trend was also significant, $F(1,36) = 6.05$, $p < .025$, and accounted for 8.3% of the variance of memory load.

There is, therefore, some indication that the negative-small test letters were processed differently from the standards, but only for the large memory loads. As a further test of this indication, multiple t tests were performed on the differences between the standard and the negative-small RTs for each of the four memory set sizes. Table 1 shows the results of this analysis. Apparently, the serial comparison process is representative of the RTs to negative-small test letters for small memory loads, but this process is not indicative of the RTs for the large memory sets. Since there were no systematic differences, other than the height of the test letters, on trials in which standard (negative) and negative-small test letters were presented, this discrepant effect of memory load may be attributed to Ss' processing of the height of the test letters.²

Errors. An analysis of variance performed on the error rates showed significant effects only of test letters (positive, negative, and negative-small), $F(2,72) = 50.87$, $p < .001$, and Test Letters by Memory Load, $F(6,216) = 2.52$, $p < .025$. The overall error rate for positive test letters was 8.49%. The error rates for negative and negative-small test letters, respectively, were 2.97% and 1.93%; this difference was not significant, $t(72) = 1.49$, $p > .1$. The large difference between positive and negative responses may simply reflect the differential response probabilities, since the overall

probability of a correct negative response was twice that of a correct positive response (cf. Hawkins, Thomas, & Drury, 1970).

The interaction of stimulus type with memory load may be more informative. These data are presented in Table 2. There is a general tendency for errors to positive test letters (misses) to increase with memory load, although this relation breaks down at the largest memory load. Errors to negative test letters (false alarms) tend to decrease with increasing memory load. These results may indicate a bias towards negative responses for larger memory loads, at least for the memory-dependent process. However, there is no systematic effect of memory load on the negative-small error rates. This discrepant effect of memory load may provide support for the assumption of independent decision stages in the memory-dependent and physical discrimination processes.

EXPERIMENT 2

While the results of Experiment 1 indicated that the item recognition process is not disrupted when S also discriminates the height of the test letter, there still remained the question of whether or not the physical discrimination process is affected by performing the memory search. Experiment 2 is an attempt to answer this question by determining the magnitude of the RTs for the size discriminations alone.

Method

The apparatus, stimuli, and procedure were identical to those of Experiment 1, with the following exceptions: (1) the Ss did not view the memory sets, (2) the task was to decide if the presented letter was the same size or smaller than the base size, and to register the decision by pressing one of two response keys, and (3) the 144 trials took roughly 20 min to complete.

The Ss were 12 students drawn from the same source as in Experiment 1. They were equally divided into three groups, with each group viewing the test letters from one of the experimental conditions of Experiment 1.

Results

In Experiment 1, Ss responded overtly on the basis of the size discrimination only when the test letter was smaller than the standard. Consequently, the data of primary interest in the present experiment are the RTs for correct "smaller" judgments only. Table 3 shows the mean RT, overall error rate, and standard error for these stimuli for each S in Experiment 2.

Table 2
Percentage of Errors for Each Stimulus Type as a Function of Memory Load: Experiment 1

Stimulus Type	Memory Set Size			
	1	2	3	4
Positive	7.29	9.17	10.62	6.87
Negative	4.79	2.92	2.29	1.87
Negative-Small	1.67	2.29	1.67	2.08

Table 3
Latencies for Correct "Smaller" Judgments and Error Rates for Small Stimuli: Experiment 2

Subject	Condition								
	36:30			36:24			36:18		
	RT	SE	Percent Error	RT	SE	Percent Error	RT	SE	Percent Error
1	560	13	9.80	519	19	14.89	465	8	0.0
2	653	18	6.25	424	9	2.08	469	10	4.17
3	580	15	12.50	624	17	6.25	547	14	8.33
4	532	13	31.25	460	10	14.58	428	8	2.08
Overall Means	581	26	14.95	507	44	9.45	477	25	3.64

One way these data may be related to those of Experiment 1 is to compare them to the negative-small RTs in that experiment for the four-letter memory sets, when the response was most likely based on the size discrimination. The means for the 30-, 24-, and 18-min negative-small test letters, respectively, were 577, 531, and 511 msec. These values agree quite well with the corresponding RTs shown in Table 3: In no case is the size discrimination alone consistently faster than when the discrimination is embedded in the item recognition task; also, none of the differences between the corresponding means approaches significance (all t s < 1 , 12 df). Therefore, it appears that the Ss in Experiment 1 were able to discriminate the size of the test letters concurrently with performing the item recognition task.

Discussion

In the three experimental conditions of Experiment 1, standard test letters could be judged only after a memory search; negative-small test letters could be judged either on the basis of a memory search or a size discrimination. The data of Experiments 1 and 2 strongly suggest that Ss took advantage of this information by subjecting the test letters to two parallel and independent processes. The first process, which is dependent on the memory set, can be identified with the additive-stage model elaborated by Sternberg (1969) for item recognition: the test letter is encoded, and then serially and exhaustively compared with the letters in the memory set at a rate of approximately 40 msec per comparison. A response is then selected and executed, positive if a match has been found and negative if not.

The second process, which proceeds concurrently with the first, is independent of the memory set and is composed of the operations involved in making an absolute judgment of the size of the test letter. This process initiates a (negative) response only when a decision is made that the

height of the test letter is smaller than the standard.

Are these processes truly independent? If so, then it must be the case that factors affecting only one process do not affect the other. The data of Experiment 1 permit us to test this by looking at the operation of the item recognition process as the difficulty of the size discrimination is varied. As the difficulty of the discrimination was decreased, no significant change was found in either the slope or intercept of the standard RT function. Thus, it appears that the item recognition process is quantitatively, as well as qualitatively, equivalent at all levels of difficulty of the size discrimination process. Moreover, even in the control condition, where height discrimination of the test letters is not indicated, there is still no change in the parameters of the item recognition process. Furthermore, the results of Experiment 2, in conjunction with those of Experiment 1, suggest that the item recognition process does not affect the size discrimination. Hence, the assumption of independence appears to be justified.

Under the assumption of parallel processing, the results presented in Fig. 1 can be more deeply understood. It is assumed that the onset of the test letter initiates both the item recognition process and the size discrimination of the test letter. A response is initiated by the process which terminates first. Thus, the linear relationship of RT to memory load for the standard test letters simply reflects the usual serial comparison process found in previous item recognition studies. Furthermore, the breakdown in linearity for the negative-small test letters may be attributed to the combined effects of the two independent processes. That is, the negative-small RTs actually reflect a function, namely, the minimum value, of two linear relations: the first is determined by the additivity of the item recognition process and has the same intercept and slope as the function for standard test letters; the second, which is constant for all

memory loads, is determined by the time taken by the size discrimination.

From the graphs in Fig. 1, it is possible to estimate the time required by the size discrimination. This is done by fitting the negative-small RTs in each condition with two straight lines: The first, which determines the RTs for small memory loads, has the same slope and intercept as the standard RT function, while the second has zero slope and determines the RTs for the larger memory sets. The intercept of the second line, then, is an estimate of the duration of the size discrimination. This procedure predicts the following values: for the most easily discriminated negative-small letters, the size discrimination requires approximately 510 msec; for the intermediate negative smalls, about 518 msec; and for the largest negative smalls, about 575 msec. These predictions are in close accord with the values obtained in Experiment 2.

EXPERIMENT 3

The results of the previous experiments suggest that, at least for size information, Ss can perform the usual processes of item recognition while simultaneously making an absolute judgment of the physical features of the test letter. However, this ability may be specific to the type of physical information that is relevant. That is, it is reasonable to assume that size normalization is one of the operations performed by the encoding stage of the item recognition process (Sternberg, 1967). In this case, size is a critical feature for both the item recognition and the physical discrimination processes. On the other hand, different sources of physical information, which may be "gated" (Posner, 1964) for the purposes of the item recognition process, may not be handled in the same way. In Experiment 3, an attempt was made to generalize the parallel processing model by using the color of the test letter as the relevant physical feature.

Method

Subjects. Ten introductory psychology students who had not participated in Experiment 1 served as Ss.

Apparatus and procedure. Apparatus and procedure were the same as in any one of the experimental

Table 4
Difference Between Standard and Negative-Red RTs (Msec) as a Function of Memory Load: Experiment 3

1	Memory Set Size		4
	2	3	
17	33*	31*	66†

* $p < .05$, † $p < .01$

Fig. 2. Latency and error rate for standard and red test letters as a function of memory load for Experiment 2. Standard error rates are shown separately for positive and negative letters. The regression line and equation are shown for the standard RTs.

conditions of Experiment 1, except that the 10 Ss were instructed that red test letters were not contained in the memory sets.

Stimuli. The memory sets and test letters were again drawn from the 26 letters of the alphabet. They were typed onto the stimulus cards in uppercase elite in either black (positive and negative) or red (negative-reds). Each letter subtended 18 min of visual angle.

Results

Figure 2 shows the mean RTs for standard and negative-red test letters as a function of memory load. Only correct responses contributed to these means; overall error rate was 5.07%.

Trend analysis revealed that, for the standard test letters, RT is again a linear function of memory load; the linear trend accounted for 98.7% of the variance of memory load, while the quadratic trend was not significant, $F(1,9) = 2.15$, $p > .1$. The intercept and slope of the regression line, 439 and 41 msec, respectively, are in close accord with the values reported in Experiment 1, and again support the application of the additive item recognition model to the standard RTs.

The linear increase with memory load breaks down for the negative-red test letters. Linear regression accounts for 85.4% of the variance of memory load; however, the quadratic trend also is significant, $F(1,9) = 11.58$, $p < .01$,

and accounts for 10.3% of the variance.

Multiple *t* tests performed on the difference between standard and negative-red RTs at each memory load (see Table 4) indicate that the negative-reds are responded to significantly faster for all except the one-letter memory sets. It appears, therefore, that Ss are able to use color information to reduce their RTs below those required by the serial comparison process for two-letter or larger memory sets.

One problem, however, that these data raise for the parallel-stage model proposed earlier is the increase in RT for the negative-reds from two- to three- and four-letter memory sets. This increase is significant: for two- vs three-letter memory sets, $t(54) = 3.06$, $p < .01$; for two- vs four-letter memory sets, $t(54) = 2.65$, $p < .02$. According to the parallel model, if Ss can respond on the basis of the color discrimination before two memory comparisons are completed, then RTs for these stimuli should not increase for larger memory loads. That the RTs do increase indicates that Ss might have had difficulty in using the color information efficiently. This may well be due to the fact that some Ss did not process the color of the test letters consistently, perhaps because such information may be gated by the item recognition process. However, the significant reduction in RT for these stimuli for large memory loads does indicate that a sizable majority of the Ss were consistently able to utilize the color information concurrently with performing the encoding and search operations of item recognition.

The error data for Experiment 3 are very similar to those of the first experiment. Error rates for positive, negative, and negative-red test letters, respectively, were 9.58%, 4.58%, and 1.04%. Analysis of variance revealed that the effect of test letters was significant, $F(2,18) = 11.49$, $p < .001$. While the difference between positive and negative test letters was significant ($p < .02$), the difference between negatives and negative-reds was not [$t(18) = 1.98$, $p > .05$]. There was also a significant interaction of test letters and memory load, $F(6,54) = 2.67$, $p < .05$; as can be seen in Fig. 2, errors to positive and negative test letters vary widely as a function of memory load, but the negative-red error rate is quite stable for all memory set sizes.

GENERAL DISCUSSION

The hypothesis that item recognition and physical discrimination can occur in parallel is clearly supported by the present results. The strongest evidence in favor

of this hypothesis is that the time for item recognition alone or size discrimination alone is the same as the time for item recognition or size discrimination in a combined task. Furthermore, it was found that increasing the difficulty of the physical discrimination had no effect on the time to process the standard test letters; in fact, for small memory loads, responses based on memory comparisons were faster than responses based on size or color discriminations. There was no evidence for an initial preattentive stage that screens items for their physical characteristics before they are processed focally.

How might these results be reconciled with Neisser's (1967) two-stage theory of attention? According to this theory, during a visual search task, Ss are able preattentively to reject nontargets which can be discriminated from targets on the basis of gross physical characteristics, like size or color; only "reasonable" candidates for targets are subjected to the subsequent detailed analyses of the focal attentive processes. With the exception of Beller's (1968) indirect finding of the effect of size discrimination difficulty on preattentive and focal processing times, the bulk of the data from visual search experiments seems to support such a theory. To understand these results, a closer analysis of visual search is necessary.

Visual search is an iteration of the following gross subprocesses: (1) reject an item currently being attended to; (2) select the next item to be processed; (3) initiate an eye movement to bring the fovea to bear on the next item. But for large displays, selection of the next item must involve peripheral vision. The critical question concerns what kind of information can be processed peripherally, and the data of Williams (1966) provides a clear answer: color is processed most easily, size is processed to some extent, and form is not processed at all. Due to the large convergence of rods in the periphery, visual acuity and form discrimination are extremely poor. From these considerations alone, then, we would not expect recognition of letter forms to be possible in the periphery; form recognition must wait until an eye movement brings the item into the fovea. The empirical results in visual search concerning the successiveness of size and color judgments followed by form judgments are simply the result of the kind of information that can be processed in peripheral vision.

In fact, if we look closely at processing rates, the evidence is suggestive of parallel processing during

visual search. Williams (1966) points out that since there are about three fixations per second, there are about 300 msec devoted to each fixation. During each fixation, Ss must decide whether the item they are looking at is a target, and they must decide which item to fixate next and initiate the next eye movement. Williams suggests that 300 msec is not enough time for these decisions to be made sequentially. Given the present results, we suggest that it is possible that Ss search memory for the item in the fovea concurrently with peripheral search for another item of the appropriate size or color. The present results show that the form of an item in the fovea can be processed in parallel with size or color of the same item. For parallel processing to work in visual search, one need only suppose that size or color of another item in the periphery can be processed in parallel with the form of a foveal item. This is an empirical question; there is no a priori reason why this cannot be true.

It therefore does not seem necessary to postulate a two-stage hierarchically and sequentially organized attention process to explain the effects of size and color on visual search. One must be careful to distinguish between processes which must be completed before a second stage can begin, and processes which are not so dependent. The analysis of lines, angles, and relative size judgments would seem to be necessary before form recognition can occur. And Sternberg (1967) has suggested that form recognition must precede a target-nontarget memory comparison. But it seems clear at this point that judgments of color and absolute size are not necessary precursors to the analysis of letter forms. Although size and color can be used to direct the fovea onto appropriate parts of the visual field, it is misleading to call these judgments preattentive in the strong sense of Neisser (1967).

Perhaps a more appropriate

approach to the understanding of these processes is that of Posner and Keele (1970). They operationally define attention in terms of interference: when the performance of one simultaneous task interferes with the other, the tasks are said to require attention. To understand attention, they suggest, involves knowing how the interference arises. Keele (1970) has further suggested that more than one stimulus attribute can contact memory without interference, but subsequent mental operations (e.g., transformations, storage, response decisions) on these stimuli must be done serially. Keele also suggests that if multiple sources of information are combined into a single response, there is no interference. The present experiments conform to these conditions and further confirm Keele's conclusion.

REFERENCES

- BELLER, H. K. Stages of processing in visual search. Unpublished doctoral dissertation, Brandeis University, 1968.
- GOULD, J. D., & DILL, A. B. Eye-movement parameters and pattern discrimination. *Perception & Psychophysics*, 1969, 6, 311-320.
- GREEN, B. F., & ANDERSON, L. K. Color coding in a visual search task. *Journal of Experimental Psychology*, 1956, 51, 19-24.
- HAWKINS, H. L., THOMAS, G. B., & DRURY, K. B. Perceptual versus response bias in discrete choice reaction time. *Journal of Experimental Psychology*, 1970, 84, 514-517.
- KEELE, S. W. The locus of attention. Unpublished manuscript, University of Oregon, 1970.
- NEISSER, U. Decision time without reaction time: Experiments in visual scanning. *American Journal of Psychology*, 1963, 76, 376-385.
- NEISSER, U. *Cognitive psychology*. New York: Appleton-Century-Crofts, 1967.
- POSNER, M. I. Information reduction in the analysis of sequential tasks. *Psychological Review*, 1964, 71, 491-504.
- POSNER, M. I., & KEELE, S. W. Time and space as measures of mental operations. Invited address to the American Psychological Association, September 1970.
- SMITH, E. E. Choice reaction time: An analysis of the major theoretical positions. *Psychological Bulletin*, 1968, 70, 77-110.
- SMITH, S. L. Color coding and visual

- search. *Journal of Experimental Psychology*, 1962, 64, 434-440.
- STERNBERG, S. High speed scanning in human memory. *Science*, 1966, 153, 652-654.
- STERNBERG, S. Two operations in character recognition: Some evidence from reaction-time measurements. *Perception & Psychophysics*, 1967, 2, 45-53.
- STERNBERG, S. Memory-scanning: Mental processes revealed by reaction-time experiments. *American Scientist*, 1969, 57, 421-457.
- WILLIAMS, L. G. The effect of target specification on objects fixated during visual search. *Perception & Psychophysics*, 1966, 1, 315-318.

NOTES

1. However, there were two significant points of departure between the present results for standard test letters and Sternberg's findings. The first was a differential effect of memory load on the positive and negative RTs, with a greater slope for the positive test letters. Such a result is not consistent with either a simple self-terminating or an exhaustive comparison process, as Sternberg has viewed them. The second deviant result was the finding of large serial position effects for the positive test letters; with a memory load of four items, latencies increased by about 40 msec per item from first to fourth serial position. This result is contrary to an exhaustive search model (and to the above-mentioned finding, as well). Since both of these effects were manifested at least as strongly in the control condition as in the experimental conditions, it is difficult to attribute them to the effects of additional processing required in the latter. At present, there is no explanation for these results. What their implications are, in fact, for Sternberg's additive-stage model must await further research.

2. This conclusion is slightly weakened by the significant difference between standard and negative-small letters for Size 4 memory sets in the control condition, where Ss were reportedly not discriminating the height of the test letter. This finding may imply some systematic bias in the construction of the stimulus sets. On the other hand, it is possible that control Ss were affected by the heights of the test letters, but not consciously. It is not possible to resolve this question on the basis of the present data. However, at the .01 level of significance, only the smallest negative-small test letters show differential processing for large memory loads. This finding is in support of the conclusions stated in the text.

(Accepted for publication May 1, 1971.)