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TEST STIMULUS REPRESENTATION AND EXPERIMENTAL CONTEXT EFFECTS IN MEMORY SCANNING[1]

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The *S*s performed a memory-scanning task in which they indicated whether or not a given test stimulus (letter or picture) matched one of a previously memorized set of letters. The test stimuli presented during a given session were either exclusively letters (a letter session), exclusively pictures (a picture session), or a random sequence of both (a mixed session). Reaction-time functions relating response latency to the size of the memorized set of letters were plotted, and the data are discussed in the context of the scanning models previously proposed by S. Sternberg. The reaction time functions of letter sessions and picture sessions were found to be consistent with the exhaustive model for memory scanning. However, the functions for mixed sessions deviated markedly from the predictions of such a model. The context in which a scanning task is imbedded appears to have a substantial effect on reaction time functions.

Evidence that scans of information stored in short-term memory are serial and exhaustive has been presented in several experiments using a task proposed by Sternberg (1966). In this task, *S* pulls one of two levers to indicate whether or not a given *test stimulus* matches any item in a previously memorized set (the *memory set*). If a match occurs, *S* makes a positive response; otherwise, a negative response. In theory, *S* stores a representation of the memory set in short-term memory before the test stimulus is presented. His performance on the task then involves three stages. First, the test stimulus which appears is processed and transformed so that it is comparable to the memory set. Next, *S* scans the memory set and compares its elements to the test stimulus. Finally, a decision is reached on the basis of these comparisons.

Two models for this memory-scanning task have been proposed by Sternberg (1966). If the test stimulus representation is compared to every member of the memory set before a response is made (regardless of whether or not a match occurs prior to completing the comparisons), the scan is *exhaustive*. However, *S* could terminate the comparison process and respond immediately after obtaining a match; such a scanning process would be *self-terminating*. For each model, equations can be derived relating reaction time (RT) to the size of the memory set (d). For the exhaustive case,

$$\mathrm{RT}(d) = \begin{cases} (\pi + \rho_p) + d\kappa, & \text{for a positive response} \\ (\pi + \rho_n) + d\kappa, & \text{for a negative response.} \end{cases} \quad [1]$$

for the self-terminating case,

$$\mathrm{RT}(d) = \begin{cases} (\pi + \rho_p) + \tfrac{1}{2}(d + 1)\kappa, & \text{for a positive response} \\ (\pi + \rho_n) + d\kappa, & \text{for a negative response.} \end{cases} \quad [2]$$

In these equations π = initial test stimulus processing time, κ = time for a comparison with one memory-set element, ρ = response time, and the subscripts p and n refer to positive and negative response, respectively.

In one of Sternberg's (1966) experiments, which used digits as stimuli, he found that the RT functions were linear and increasing. This supports the hypothesis that elements of the memory set are scanned

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serially. In addition, the functions had equal slopes for both positive and negative responses. This conforms to the predictions of the model for an exhaustive scan of memory.

The results obtained by Sternberg (1966) for digits have been replicated for other stimuli. For example, Sternberg (1969) found similar results for faces and nonsense forms as well. He also found that the RT functions were consistent with the model for serial exhaustive scans when stimuli were degraded (i.e., presented with a superimposed grid; Sternberg, 1967).

A recent study by Wingfield and Branca (1970) shows comparable results obtained with both digits and letters. The size of the memory set in their experiments varied from 1 to 12 elements. Again, linear RT functions were obtained (although in the case of digits, *S*s searched through the complement of the memory set when the memory-set size exceeded the size of the complement), and there was no difference between the time required for a positive response and that required for a negative response.

Briggs and Blaha (1969) varied both the size of the memory set and the number of simultaneously presented test stimuli in a task similar to the Sternberg (1966) paradigm. The stimuli consisted of 24 eight-sided geometrical forms, 8 of which were designated as positive and 16 as negative. On a given day, *S* participated in trials with one particular memory-set size (one, two, or four), while the test-set size varied. That is, before each session, *S* was told which particular positive set element(s) would be used. His task was to make a positive response if one of the test stimuli was a member of the positive set. For each test-set size (one, two, or four), Briggs and Blaha obtained RT functions (RT plotted as a function of memory-set size) which were linear and increasing. Moreover, when there was a single test stimulus, the slopes of the functions for positive and negative responses were identical. Again, the results support the hypothesis that *S*s perform a serial exhaustive search of memory in this task.

Although the studies described above indicate that data resulting from the Sternberg paradigm fit the model for exhaustive scans of memory, a recent study (Klatzky & Atkinson, 1970) implies that an exhaustive search need not always occur. Under some conditions, it appears that the obtained data correspond to the predictions of the self-terminating model for memory scanning.

The conditions under which findings were more characteristic of self-terminating memory scans were the following: *S*s committed to memory a set of two or four letters. They were then tested with one of three possible types of test stimuli: a letter, word, or picture. If the test stimulus was a letter, *S* made a positive response only if that letter matched one of those in the memory set. (This is simply a Sternberg paradigm in which letters are used as stimuli.) If the test stimulus was a word, *S* made a positive response only if the initial letter of that word was contained in the memory set. Finally, if the test stimulus was a picture, *S* made a positive response only if the first letter of the name of that picture was a member of the memory set.

The data obtained from this task suggested that memory scans could be self-terminating. In particular, the ratio of the slope of the RT function for negative responses to the slope for positives was about 1.75 for letters, words, and pictures. These data led to the following hypothesis: When presented with a picture-test stimulus, *S* transforms that picture into a verbal representation (i.e., a label) which is subsequently used for comparisons with the memory set. Such comparisons are slower than those which could be made with a visual representation (i.e., one based on the physical features of the stimulus), and the scan of memory is self-terminating in this case. On the other hand, the presentation of a letter-test stimulus has mixed effects. If the stimulus is transformed into a verbal representation which is used for comparisons with the memory set, these comparisons are self-terminating. In contrast, the stimulus representation could be visual in nature, and this would result in an exhaustive search of memory. The latter strategy is comparable to that used by *S*s in Sternberg's (1966) experiment.

The present research was conducted in an attempt to clarify the results of the study by Klatzky and Atkinson (1970) and several modifications were, therefore, introduced. The task was simplified by the elimination of word stimuli; test stimuli were either letters or pictures. There were three types of test sessions, using either pictures only, letters only, or a random mixture of letters and pictures as test stimuli. Moreover, additional memory-set sizes were added; a memory set consisted of two, three, four, or five letters. In all cases, *S*'s task remained the same as before; i.e., if the test stimulus was a letter, *S* made a positive response if that letter was included in the memory set. If the test stimulus was a picture, a positive response was made only if the name of that picture was a word beginning with one of the letters in the memory set.

Method

Subjects.—The *S*s were 12 female students at Stanford University. They were paid $2.00 for each of 10 experimental sessions.

Stimuli.—The memory-set stimuli consisted of 72 slides prepared from photographs of letters typed with an IBM Executive Registry electric typewriter. A dollar sign ($) was placed at each end of the display to delimit it; there were no spaces between the ends of the display and their delimiters. The set of letters used in memory-set displays consisted of all members of the alphabet but the five vowels and V, X, and Y; this set of letters will be referred to as the *letter set.* Each member of the letter set was used equally often in each serial position in memory sets, and no letter was duplicated within a memory set.

There were two types of test stimuli, letters and pictures. Letter-test stimuli were displayed on slides which were prepared in the same manner as memory-set displays. However, no dollar signs were present on letter slides. There was a letter stimulus corresponding to each member of the letter set. Also corresponding to each letter-set element were three picture-test stimuli. All three stimuli represented a single common noun whose first letter was the member of the letter set (e.g., there were three pictures of dogs used as stimuli, each representing the letter D, three snake pictures for the letter S, etc.). These pictures were presented on slides prepared from photographs of black-and-white drawings.

Apparatus.—The apparatus consisted of an Iconix automated tachistoscope and exposure box. The controls of the apparatus were located in an adjacent room, where a punched paper tape, which was read by a teletype, controlled the sequence of trial events. The data of each trial were punched automatically onto a paper tape and also printed by a teletype.

The stimuli were presented to *S* through a circular aperture onto a viewing screen, illuminating a circle with a diameter of $2\frac{1}{16}$ in. The projections of memory-set displays were $\frac{3}{16}$ in. high, and their width varied from $\frac{1}{2}$ in. for a display of Size 2 to $\frac{7}{8}$ in. for a display of Size 5. The picture slides, when projected, had both a maximum height and a maximum width of $2\frac{1}{16}$ in., the diameter of the viewing circle. The line of sight viewing distance was approximately 2 ft.

Between stimulus exposures, a circular field was presented with a brightness of 6.6 ftl. A black dot was placed in the horizontal center and slightly above the vertical center of the field as a fixation point. The brightness of the field during stimulus presentations was approximately 3.5 ftl.

Above the viewing aperture, three small colored lights could be illuminated. These were used to indicate to *S* whether or not a response was correct. Below the viewing screen was an IEE Binaview unit which was used to signal *S* to begin the test portion of the trial.

On a table in front of *S* were three telegraph keys arranged in an arc, with their centers separated by a distance of 1.25 in. The *S* rested her right arm on the table and depressed the keys with her right forefinger. Six *S*s were chosen at random to press the key on the right for a positive response and the key on the left for a negative response, and the remaining *S*s used the reverse procedure. Each *S* was instructed to depress the center key until she was ready to respond, so that her hand position was not biased in favor of either of the response keys.

Procedure.—Each *S* participated in one training session and nine additional test sessions of 160 trials each; each session lasted about 50 min. The test sessions were of three types: in letter sessions, only letters were used as test stimuli; in picture sessions, only pictures appeared on tests; and in mixed sessions, letters and pictures appeared equally often in a random sequence. The first, or training session for each *S* consisted of a sequence of 40 trials which used only letters as test stimuli, 40 trials using pictures, and finally 40 trials where both letters and pictures occurred randomly as test stimuli. After this training session, *S* subsequently participated in three letter sessions, three picture sessions, and three mixed sessions. The *S*s were assigned to sessions according to a modified Latin-square design in which the nine test sessions were divided into three blocks of three sessions each. Within a block, each type of session occurred once, and the order of occurrence remained the same for all three blocks

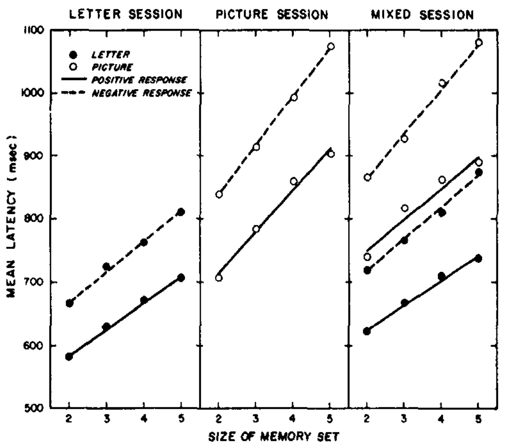

FIG. 1. Latency in milliseconds of positive and negative responses for letter (left panel), picture (center panel), and mixed (right panel) sessions as a function of memory-set size, averaged over *S*s and blocks.

for a given *S*. Over all *S*s, each type of session was used equally often in each of the nine test-session positions.

Each memory-set size (two, three, four, or five), each response (positive or negative), and each serial position for a correct response (the position of the test stimulus in the memory set, numbered from left to right) was randomly chosen with equal probability for use in a given session; and on the average, each was used equally often in a session. In addition, during mixed sessions, letters and pictures were used with approximately equal frequency for each set size, response, and serial position. Within the above constraints, the particular stimuli which occurred on any trial were randomly selected.

At the beginning of picture and mixed sessions, copies of the pictures which were to be used as test stimuli were shown to *S* and named by her before she began the series of 160 trials. Each trial lasted approximately 16 sec., and consisted of the following sequence of events. (*a*) A memory set, delimited by dollar signs, appeared on the screen in front of *S* for 2 sec. (*b*) About 5 sec. later, a visual signal consisting of a flash of the Binaview unit and an auditory signal of two clicks indicated to *S* to begin the test when she was ready. (*c*) The *S* pushed a button held in her left hand, and after a delay of 500 msec., the test stimulus appeared on the screen for 2 sec. (*d*) Using her right hand, *S* responded by lifting her forefinger from the center key and depressing the key to the right or left. (*e*) A red, green, or white light then appeared on the screen, indicating whether *S* had made an incorrect response, had made a correct response, or had exceeded a 2-sec. limit on the time allotted between the test stimulus onset and her response, respectively. (*f*) After an interval of 5 sec., the next trial began

The *S*'s response time was recorded by a latency counter, the onset of which was simultaneous with the onset of the test stimulus. The counter was terminated when the key to the right or left was depressed.

There were three short rest periods in the session, occurring after Trials 40, 80, and 120. During this time, *E* entered *S*'s room to change slide drums for the projector. Each rest period lasted approximately 2 min.

Results

The data consist of mean latencies in milliseconds. (The latency of a response is defined as the time between the onset of the test stimulus and *S*'s depression of the right or left key.) The data analysis includes the data for correct responses only; however, the error rates were quite low. The maximum error rate for an individual *S* was 3.25%; the minimum was .92%; and the overall error rate was 2.00%. In addition,

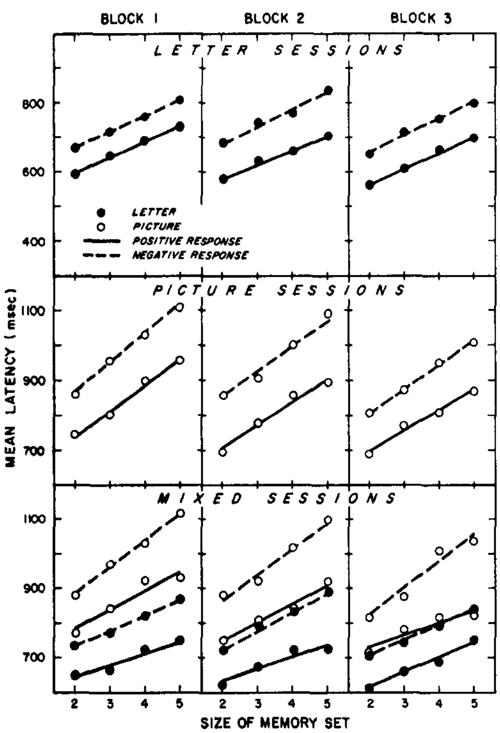

FIG. 2. Latency in milliseconds of positive and negative responses for the letter, picture, and mixed sessions of each block (1, 2, or 3) as a function of memory-set size. (Data are averaged over *S*s.)

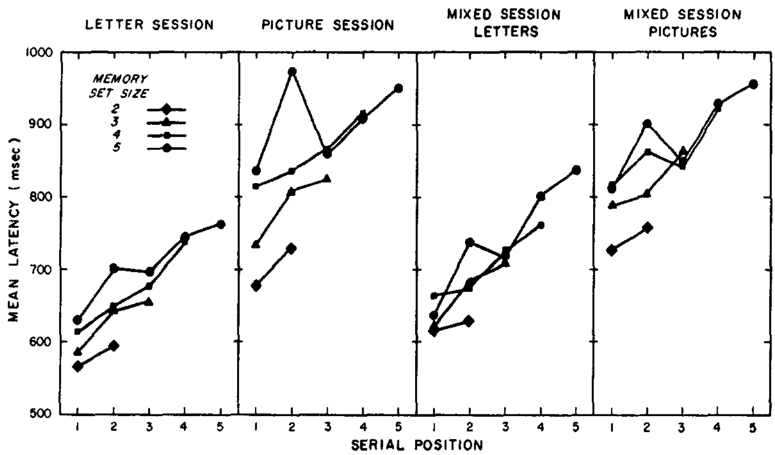

FIG. 3. Latency in milliseconds of positive responses as a function of the serial position of the test stimulus in the memory set for sets of 2, 3, 4, or 5 elements and for each type of session and stimulus. (Data are averaged over *S*s and blocks.)

the first six trials of each test session were considered warm-up trials, and the data from these trials were not included in the analysis. Data from the initial training sessions were also excluded.

In Table 1, the data broken down into blocks of three sessions each, as well as averaged over all blocks, are presented. Block 1 consists of Test Sessions 1–3 and contains the first letter session, the first picture session, and the first mixed session for each *S*, and so on for the other blocks. Slopes and intercepts were fit to the data by the method of least squares, and in the table, the slopes (S_n; S_p), intercepts (I_n; I_p), and slope ratio (S_n/S_p) of the RT functions, as well as the error percentages (E_n; E_p), are given for each type of session and each response (where the subscripts *n* and *p* refer to negative and positive responses, respectively). Note that the slopes and intercepts for the overall mean refer to the RT functions fit to the mean data; they are not the means of the slopes and intercepts for each block. In addition, for all functions the slope ratio is not the mean of the ratios of individual *S*s, but rather the ratio of the slopes calculated for the mean data over *S*s.

The RT functions for each type of session and each response, showing mean latency as a function of the size of the memory set, are presented in Fig. 1 and 2. In Fig. 1, the functions are the best fitting straight lines for the average data over all blocks and all *S*s. In Fig. 2, the data are broken down into blocks. Thus, Block 1 refers to the first session of a given type, Block 2 to the second, and Block 3 to the third.

The serial position curves for correct responses are shown in Fig. 3. These show plots of the mean overall latency for a correct

TABLE 1

SLOPE AND INTERCEPT VALUES OF THE REACTION-TIME FUNCTIONS; SLOPE RATIOS; AND ERROR PERCENTAGES FOR EACH TYPE OF SESSION, STIMULUS, AND RESPONSE OF EACH BLOCK AND OVER ALL BLOCKS

Block		S_n	S_p	S_n/S_p	I_n	I_p	E_n	E_p
Letter	1	45.0	43.4	1.04	581.6	514.4	.72	1.93
session	2	49.1	40.2	1.22	587.4	503.6	.81	1.36
	3	49.0	46.5	1.05	557.4	467.6	1.14	1.94
Overall		47.0	41.6	1.13	576.6	500.9	1.16	1.49
Picture	1	80.8	73.9	1.09	708.9	594.8	.65	5.10
session	2	79.8	66.8	1.19	684.9	573.2	1.95	3.56
	3	68.1	59.3	1.15	670.8	575.2	1.00	2.96
Overall		78.9	66.5	1.19	679.0	580.0	1.32	3.59
Mixed	1	44.3	36.1	1.23	644.6	571.0	1.12	1.65
session,	2	55.1	34.6	1.59	617.9	565.7	1.92	1.34
letter	3	44.9	46.2	.97	613.2	515.3	.58	1.51
Overall		51.6	38.2	1.35	611.7	550.7	1.04	1.66
Mixed	1	75.8	54.9	1.38	734.4	676.8	2.21	5.08
session,	2	75.0	54.8	1.37	716.4	636.4	2.89	2.79
picture	3	80.4	35.7	2.25	653.6	655.1	2.58	2.05
Overall		73.6	49.3	1.49	714.8	653.6	2.36	3.52

Note.—Abbreviations: S = Slope, I = Intercept, E = Error; subscripts, *n* = negative response, *p* = positive response.

positive response as a function of the position of the test stimulus in the memory set.

Discussion

In terms of Sternberg's (1966) models, the data for letter sessions seem best explained by the hypothesis that *S*s are performing a serial exhaustive scan of memory. The RT functions for both positive and negative responses are linear, and a least-squares fit to the data yields the functions $RT(d) = 500.9 + 41.6d$ and $RT(d) = 576.6 + 47.0d$, respectively, where d represents the size of the memory set. The ratio of the slope for negative responses to the slope for positive responses is 1.13. (A ratio of 1.0 indicates that the scan is exhaustive, whereas a ratio of 2.0 would be expected if the scan were self-terminating.) Thus, these data are comparable to Sternberg's data for digit stimuli and are what would be expected on the basis of other experiments which have used this paradigm (e.g., Briggs & Blaha, 1969; Wingfield & Branca, 1970).

Similar evidence for exhaustive scanning is found in the case of picture sessions. Here, the RT functions are best fit by the equations $RT(d) = 580.0 + 66.5d$ and $RT(d) = 679.0 + 78.9d$ for positive and negative responses, respectively. Again, the slope ratio of 1.19 is close to unity; in fact, a paired t test indicates that the difference between the slope ratios of letter and picture sessions is not significant. Thus, just as when a letter is the test stimulus, the exhaustive scanning model is more consistent with these data.

It is important to note that the slope of the negative RT function, which represents the time needed for a single comparison with a memory-set element, is almost twice as large for picture sessions as the negative slope for letter sessions. This indicates that these test stimuli differ with respect to the comparisons which are made with the memory set. When a picture is presented, *S* must convert that picture to its name and then to the first letter of that name before he can form a representation of that letter to use for comparisons. If the test stimulus is a letter, however, *S* can immediately form a representation to compare with the memory set. One might hypothesize that the comparison process which follows a picture stimulus is the same as the comparison which follows the presentation of the corresponding letter as a test stimulus. In this case, the difference in processing time between letters and pictures would be reflected in a difference in the intercepts of the corresponding RT functions, and the slope of the RT function for negative responses would be the same for picture sessions as the slope for letter sessions. Since the two slopes are not identical, the data refute this hypothesis, indicating instead that the comparison process for letter sessions is not the same as for pictures.

It is possible that the difference in comparisons performed during letter and picture sessions is the result of a difference in the test stimulus representations which are compared. The representation could consist of visual features when letters are presented and a verbal label when pictures are presented, as hypothesized by Klatzky and Atkinson (1970). However, in that study the scans of memory appeared to correspond to a self-terminating theory, whereas the present data for picture sessions are more like those expected from an exhaustive scan.

The apparent difference between the scanning strategies implied by the two experiments (Klatzky & Atkinson, 1970; and the present study) is reduced when the data for mixed sessions are considered. In these sessions, which most closely approximate in procedure the sessions of the previous study, the results again depart from the model assuming exhaustive scans. The present experiment offers some indications that *S* does not always perform an exhaustive search during mixed sessions, especially when the test stimuli are pictures. The slope ratios for the overall data are 1.35 and 1.49 for letters and pictures, respectively.

An analysis of the data for each type of session by blocks, as presented in Fig. 2, yields more information about *S*'s scanning process. There is essentially no difference between blocks with respect to the forms of the RT functions for letter sessions and picture sessions. The slope ratios for all three blocks for both types of sessions are near unity and thus, characteristic of the exhaustive model.

There is a distinct difference, however, in the forms of the functions for mixed sessions when the first two blocks are compared to the third. The slope ratio for mixed sessions is in the neighborhood of 1.4 for each of the first two blocks and both types of test stimuli. The slope ratios for the mixed sessions of the third block, in contrast, are .97 for letter stimuli and 2.25 for pictures. According to the predictions of the Sternberg models, this suggests that during the third mixed session, a self-terminating scan is used when pictures are presented, whereas the scan is exhaustive for letter-test stimuli. One could argue that the data for this third session are more representative of the scanning process than those of the first two, because *S* has had more time to become accustomed to the task. This argument is somewhat supported by the block-to-block error rates; the mean error for mixed trials is 2.3% for Block 1 and 2.1% for Block 2, dropping to 1.7% for the third block. The average RT for all trials of mixed sessions also decreases slightly, from 841.4 in the first mixed session and 826.2 in the second to 790.6 in the third.

In summary, the application of Sternberg's theory to the RT functions leads to the following hypothesis about the search processes used in the task. The *S* exhaustively scans memory when the test stimuli are either all lettters or all pictures. However, when the test stimuli are mixed, the scan is not necessarily exhaustive. In the mixed condition, self-termination is likely to occur when test stimuli are pictures, especially after *S* has had extensive practice in the task. The presentation of a letter-test stimulus may also lead to a self-terminating scan when stimuli are mixed. With well-practiced *S*s, scanning appears to be exhaustive during letter sessions, during picture sessions, and during letter trials of mixed sessions; whereas, it appears self-terminating during picture trials of mixed sessions.

Additional information can be obtained from the serial position curves of Fig. 3. If these curves had slope values of zero, an exhaustive search or a self-terminating scan with a random starting position would be indicated. However, the curves show increasing trends in all cases. This is inconsistent with both of the Sternberg models, since it implies that some self-termination is occurring even though the slope ratio for yes and no responses is close to unity.

As in the original experiment by Klatzky and Atkinson (1970), the present data do not unequivocally support either of the scanning models, self-terminating or exhaustive. If the RT functions alone are considered, the data seem to fit the predictions of the exhaustive model when the task is simply a Sternberg paradigm using letters. When the translation of a picture into a letter is required for use in the paradigm, exhaustive scanning is also indicated by the functions. However, the increasing serial position curves do not support such an interpretation of the data.

The results of the mixed sessions replicate the Klatzky and Atkinson (1970) study in that the data do not support either the self-terminating or the exhaustive strategy. In fact, it appears that the scanning process changes during the course of the experiment and is not the same during mixed sessions as during letter and picture sessions. Only the third mixed session shows the RT functions with slope ratios of approximately 1.0 or 2.0 which would be predicted by the Sternberg models. Again, the serial position curves suggest that some self-termination is taking place for both letters and pictures.

The models proposed by Sternberg (1969) represent memory scanning in terms of one processor which he has called the "homonculus." The homonculus scans the material in memory serially, sending it to a comparator which signals a match register if a match is made. Another function of the homonculus is to check the match register and initiate a response if a marker from the comparator is found there. These two operations, scanning and checking, are mutually exclusive. Thus, memory scanning is either self-terminating (i.e., the match register is checked after every scan) or exhaustive (i.e., the register is checked only once, after the completion of all scans), depending on the time required for each operation.

Holmgren (1970) has suggested that self-termination might take the form of a tendency to end the search after a match has been obtained, although termination need not immediately follow the match. This idea of self-termination suggests that scanning may continue even when a match signal has been found; i.e., that the response process and the scanning operation are in some sense independent. This implies, in turn, that the separation of processing strategies into self-terminating versus exhaustive is somewhat artificial. Apparently, what is needed is a model for memory scans incorporating operations of responding and scanning which are somewhat independent. The *S* might divide his attention between these operations or attend to only one.

The way in which attention is allocated must be a function of the context in which a scanning task is imbedded, as well as the nature of the task itself. This is implied, for example, by a comparison of picture sessions and picture trials of mixed sessions. The data differ in these two situations, although the task is precisely the same. Thus, the hypothesized interaction between the response and scanning operations corresponds to what Atkinson and Shiffrin (1968) have termed a control process. That is, it can be modified, depending on such variables as the task context, instructions, and nature of the stimuli, and it is not a fixed feature of the information-processing system.

A model which describes memory scanning in these terms could predict results which fit the Sternberg models. In addition, the application of this point of view to the theory of the scanning process could account for both linear RT functions and variable slope ratios. Such a model could, therefore, fit the data of the present experiment, which the Sternberg models alone seem inadequate to explain.

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