Metered memory search[1, 2]

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Subjects stored circular sequences of letters and digits in memory. There were three types of sequence: ordered (O), backward (B), and arbitrary (A). Printed stimuli from a sequence were presented, and S transformed a stimulus by writing the item in the sequence T (=0,1,2) steps away from the stimulus. Results indicated that response time was an approximately linear function of transformation size. This finding is consistent with a metered memory search process that is serial and self-terminating. The search rates obtained suggest implicit speech as the scanning mechanism in the search process.

In an earlier study, Weber, Cross, & Carlton (1968) required Ss to store in memory circular sequences of letters and digits. The circular lists made it possible to equate frequency of both stimulus and response items, while systematically varying amount of memory processing. A stimulus from a sequence was auditorily presented, and a target response was defined as a transformation a specified number of steps, T, away from the stimulus. Reaction time between stimulus and vocal response was found to vary in an approximately linear fashion with transformation size (distance of target from stimulus). Such a result is consistent with a serial self-terminating search process in which S, starting with the stimulus, implicitly generates successive sequence items. It is necessary to have a stop rule for generation, so some kind of metering process is required to cease scanning and produce an output. Hence, when the required meter reading T is reached, S overtly responds. The search rates obtained, three to four items per second, were of the same order of magnitude as implicit speech rates (Landauer, 1962; Weber & Bach, in press).

The aims of the present study are, first, to study effects of sequence structure and material on search time and, second, to determine if a method using a written response will produce results comparable to those of Weber et al (1968).

METHOD

The design was a 3 by 3 by 2 factorial consisting of: three kinds of sequence–arbitrary (A), ordered (O), and backward (B); three sizes of transformation or address distance (0, 1, 2); and two types of sequence material (letters, digits). The sequence variable was between-Ss and the other two variables were within-Ss.

The three types of sequence were constructed as follows. Ordered (O)–the materials sequences here were in a "natural" order: for letters, a closed or circular sequence of the five letters (abcde, ab . . .);[3] for digits (12345, 12 . . .).[3] Backward (B)–the same items occurred but their order was the reverse of that above: letters (edcba, ed . . .) and digits (54321, 54 . . .). Arbitrary (A)–once more the same items were used but in an arbitrary order: for letters (edacb, ed . . .) and for digits (54132, 54 . . .).

When using the same items for each sequence type, it was not possible to control for transitional frequency between letters (such frequency would presumably be constant for digits). However, letter frequency was readily assessed, and mean S-R frequencies of zero-, first-, and second-order transitions are shown in Table 1. A high value corresponds to a high frequency; and zero-, first-, and second-order transitions represent the stimulus-response relations for zero-, one-, and two-unit transformations, respectively. The frequencies are based on Underwood & Schultz (1960) and represent frequency of single-letter responses to single-letter stimuli.

Each S was shown one digit and one letter circular list, with the instruction to commit them to memory. Then a preliminary practice series was introduced to further acquaint S with each condition. The series began with presentation of a 4½ x 11 in. sheet of paper with a column of 25 typed, double-spaced, lower-case letters, five each of a,b,c,d,e in internally randomized blocks of five. In a space beside each letter, S wrote in his normal script handwriting the appropriate transformation. Thus, with the ordered sequence O, a column of stimulus letters such as a,c,d,b,e, . . . might appear, and the appropriate written responses for a one-unit transformation would be b,d,e,c,a, . . ., respectively. The S began on the signal, "Start," and said, "Stop," on completion of the 25 transformations. This time interval constituted his response time. Next, S had 25 practice letters with two-unit transformations, in which the appropriate written response was two steps removed from the stimulus. Then he received 25 practice letters requiring a zero-unit transformation in which S simply copied the stimulus letter. The practice then continued with transformation of the digit sequences. Twenty-five digits were given for each of the corresponding digit transformations of zero, one, and two units. An analogous procedure was followed with other Ss in the A and B sequence conditions. Next, S was instructed that experimental trials were forthcoming, and that he was to transform items, as rapidly as he could, from top to bottom of the page, but that he should not make more than three or four errors on the 25-line page.

The experiment proper involved 24 response pages (four pages of 25 letters for each of the six within-S conditions). After every sixth response page there was a blank sheet for a rest period, and for each S a booklet was prepared consisting of response and rest pages. A different order of the two materials and three transformation sizes was used for each S. Between each block of six pages, there was a 1-min rest period. Between pages within a block, there was a period of about 15 sec while E recorded response time on a prepared sheet. The S was not informed of his response times.

The Ss were volunteers, either college students or student wives. There were 12 Ss, four for each of the three between-S sequences. They were randomly assigned to sequence types according to order of appearance.

RESULTS

The principal results are shown in Fig. 1 where response time is shown as a function of transformation size, sequence, and material. There is a large effect attributable to transformation size, and it is very regular for even individual Ss. Each function corresponds to 16 observations (four Ss by four blocks), and the number of strictly monotonic relations (response time increasing with transformation size) out of the 16 possible is given to the right of the corresponding function. The most variable function, BL, had 13 out of 16 monotonic relations, with most of the aberration due to one S who was unusually slow for the one-unit transformation. With the exclusion of this one S, all functions would have been passably linear.

For each sequence type, mean processing time was more rapid for digits than for letters. This result was fairly consistent across Ss and transformation sizes. With one exception, 13 or more of the 16 comparisons for each sequence condition showed faster times for digits than for

Table 1
Mean Frequency of S–R Letter Pairs

Transition Order (Transformation Size)	Letter Sequence		
	Ordered	Backward	Arbitrary
0	5.6	5.6	5.6
1	22.6	16.4	16.2
2	10.2	15.4	18.8

a. Based on Underwood & Schultz (1960; Appendix F, p. 375). These frequencies are based on a maximum possible frequency of 273.

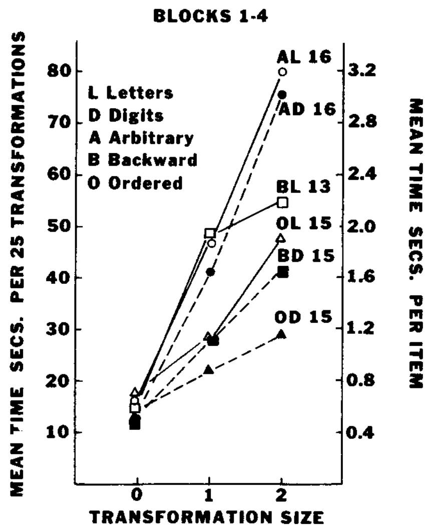

Fig. 1. Response times as a function of transformation size and sequence. The left ordinate indicates time to complete a 25-item list; the right ordinate is a conversion to time per item obtained by dividing by 25. The number in parentheses beside each function indicates the number of monotonic relations obtained out of a possible 16.

letters. The exception was Condition A2, in which only 10 of the 16 comparisons revealed more rapid processing for digits.

Examination of Table 1 shows that letter frequences bear little relationship to mean processing times. To take but one instance, zero-order transitions show the lowest mean frequency, but the zero-unit transformation was performed the most rapidly.

Error rates for the various conditions were extremely low, even though the instructions were designed to encourage a moderate number of errors. The highest error rate was 1.8% (Condition AL2), and the lowest error rate was 0.0% (several of the zero transformation conditions).

There were practice effects over blocks. The best way to describe these effects is in terms of processing rates. For each block, the reciprocals of the slopes of functions similar to those in Fig. 1 would give a measure of items per second searched through memory. For the slowest condition, AL, the search rate (reciprocal) varied from about one-half to one item per second from Block 1 to Block 4. In the most rapid condition, OD, search rates varied from about three to four items per second from Block 1 to Block 4.

DISCUSSION

Clearly the nature of the sequence is important. This is shown in two ways. First, for the larger transformations, if letters and digits are considered separately, processing rates show an increase corresponding to the sequences A, B, and O, respectively. Second, for a given kind of sequence the stimulus material is important; search rates are more rapid for digits than for letters. The reasons for these effects are not clear-cut, since storage and retrieval demands required by the six sequences are fairly minimal and error rates are very low.

It is possible that digits are processed more rapidly than letters because of a short-circuiting between stimulus and response items, i.e., a nonserial process in which stimulus-response pairings could bypass intervening items in the sequence. However, a nonserial process ought to produce functions that are not strictly monotonic with respect to size of transformation; this rarely occurred. Also, the differences in times for zero- and one-unit transformations cannot be accounted for on the basis of short-circuiting. Finally, high-frequency letter transitions, as shown in Table 1, might be expected to aid short-circuiting; but there is no obvious frequency relation to the results obtained, a finding consistent with the earlier study (Weber et al, 1968) which used different stimulus letters.

The present results differ substantially from those of Sternberg (1967), who obtained search rates of 25-30 items per second in a recognition memory task. The present rates (one-half to four items per second) are consistent with those of the prior study (Weber et al, 1968). Taken together with the earlier study and introspective reports, the findings of approximately linear functions and low search rates suggest an internal speech process (Weber & Bach, in press). The speech process would operate such that there is direct access to a sequence item in the zero transformation conditions, but when initiating retrieval from memory for one- and two-unit transformations, S enters the sequence at random (or some fixed arbitrary point) and begins generating items via implicit speech. He continues generating items in the sequence until the stimulus is reached, and an appropriate meter reading (size of transformation) beyond the stimulus shows up—at that time S writes out the last item generated. A possible reason for generating items would be to transfer them to an immediate or operating memory (Brooks, 1968; Posner, 1967) where they could be metered. In an ordered sequence (or after an arbitrary sequence is well learned), generation would not begin at a random point. Direct generation, starting with the stimulus, would be possible, and metering could begin immediately.

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NOTES

1. This study received financial support from the Research Foundation, Oklahoma State University, Stillwater, Okla. 74074

2. An earlier version of this report was presented at the Psychonomic Society, St. Louis, 1968.

3. The transitions from "e" to "a" and from "5" to "1" are breaks in the normal letter or digit sequence. The effects of single sequence-break transitions such as these have been found to dissipate rapidly with practice (Weber et al, 1968). So as a first approximation, the circular lists may be considered as having homogeneous transitions between adjacent items.

The effect of partially irrelevant anchors on verbal conceptual thinking

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Three groups of 200 Ss each, a total of 600 Ss, were given lists of words to categorize as belonging to specific concepts. Group 1 had no anchoring words in their list; Group 2 had 10 anchoring words not pertinent to the category in question; and Group 3 had 10 anchoring words pertinent to the category in question. Analyses of variance showed significant differences between groups. It is suggested that irrelevant words may operate in two ways, as a generalized "strength of concept" and as "content" anchors.