Two Invariances in Retrieval of Contextual Information from Memory

Saul Sternberg
Bell Telephone Laboratories
Murray Hill, New Jersey

ABSTRACT

A slow self-terminating process of "scanning to locate" was previously inferred from reaction-times for naming the item following a test item in a short memorized list. This process underlies recognition as well as recall of contextual information, and is virtually uninfluenced by large variations in degree of learning.

Paper presented at the Eastern Psychological Association meeting, April 1969.
Also, Bell Telephone Laboratories Memorandum MM 69-1221-9.

Two Invariances in Retrieval of Contextual Information from Memory[1]

Saul Sternberg
Bell Telephone Laboratories
Murray Hill, New Jersey

The starting point for this research was a contrast that arose in the results from two earlier studies of memory retrieval. In the procedures of both these studies the subject memorizes a short list of items, and then makes a response, as quickly as he can, to a test item. The first procedure is shown in Fig. 1, and is called an item-recognition task (Sternberg, 1966). On each trial the subject memorizes

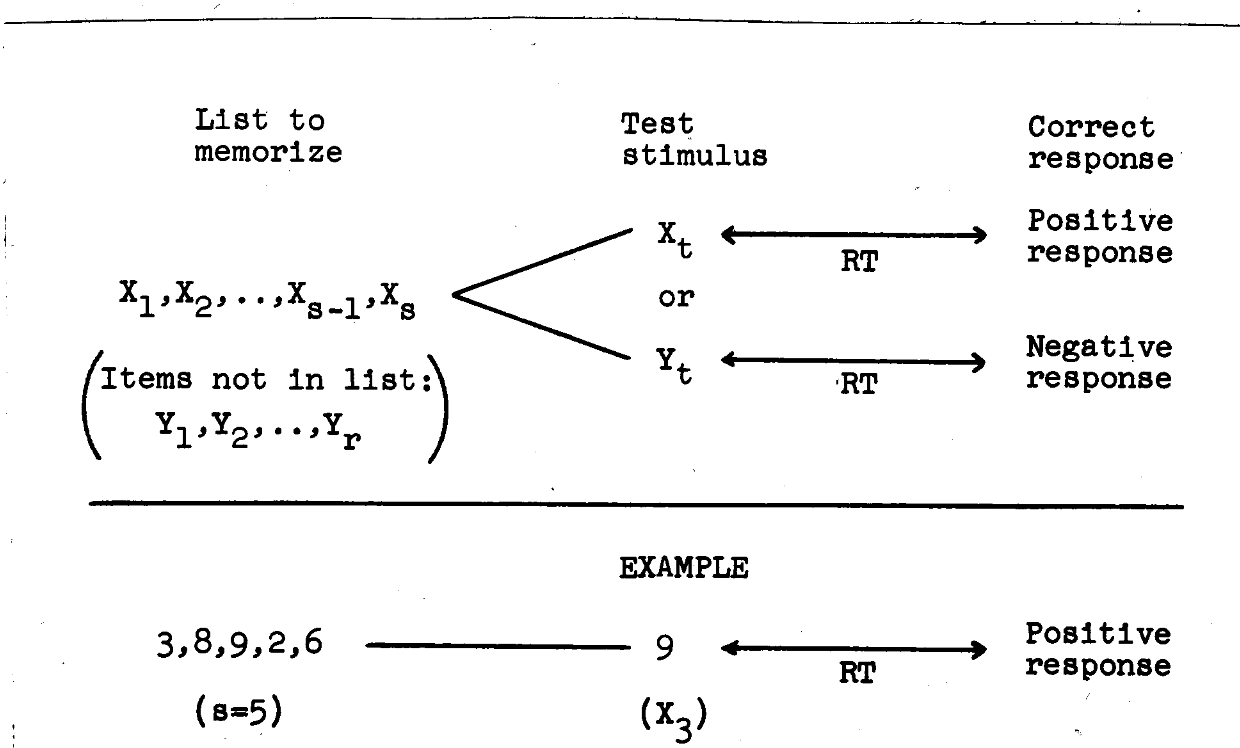

Fig. 1.

a list of s different items, for example, digits. He is then shown a test stimulus, which may or may not be one of the items in the memorized list. He makes a positive response if the test stimulus is present in the list, and a negative response otherwise. For example, if the list contained the five items 3, 8, 9, 2, 6, and the test stimulus was a 9, the correct response would be a positive response.

The second procedure is shown in Fig. 2, and is called a context-recall task (Sternberg, 1967). Again, on

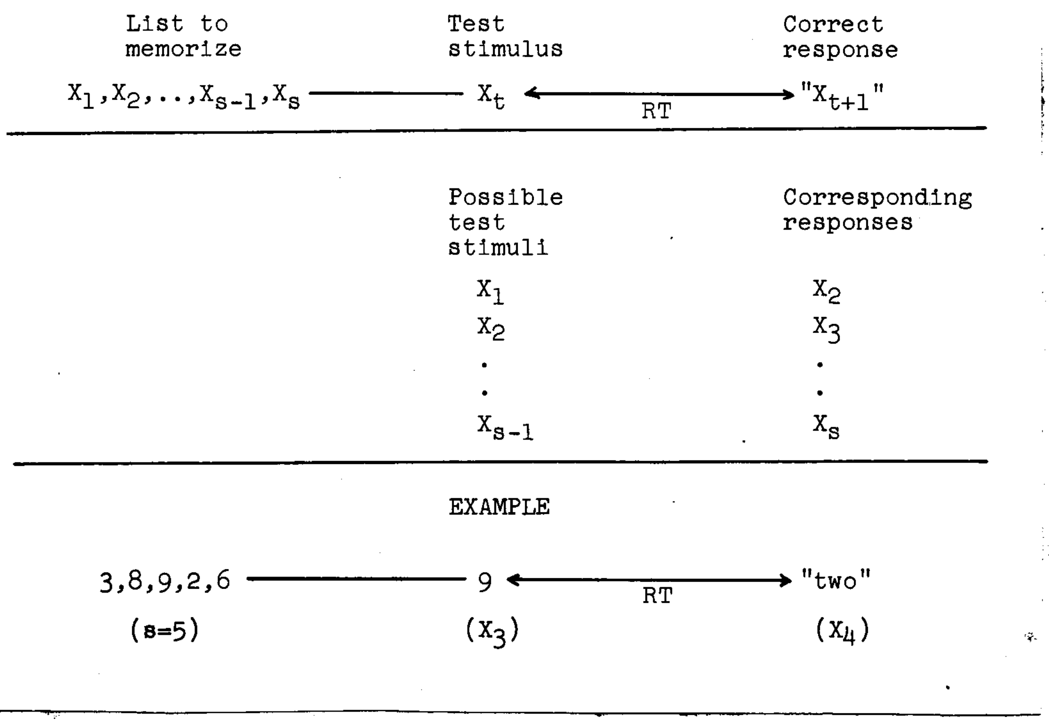

Fig. 2.

each trial the subject memorizes a list of items, and is then shown a test stimulus. Here, the test stimulus is always one of the items in the list, and can be any one except the last. The correct response is the spoken name of the item that followed the test item in the list. For example, if the list contained the five items 3, 8, 9, 2, 6, and the test stimulus was a 9, which is the third item in the list, the correct response would be "two", the fourth item in the list. I call this a context-recall task because the correct response is an item defined by its contextual relation to the test stimulus.

In Fig. 3 are shown reaction-time data from these two procedures that are typical of those that I have obtained from groups of subjects in earlier experiments.[2] Mean reaction-time is plotted as a function of the length of the memorized list. For each list length, data have been averaged over serial positions.

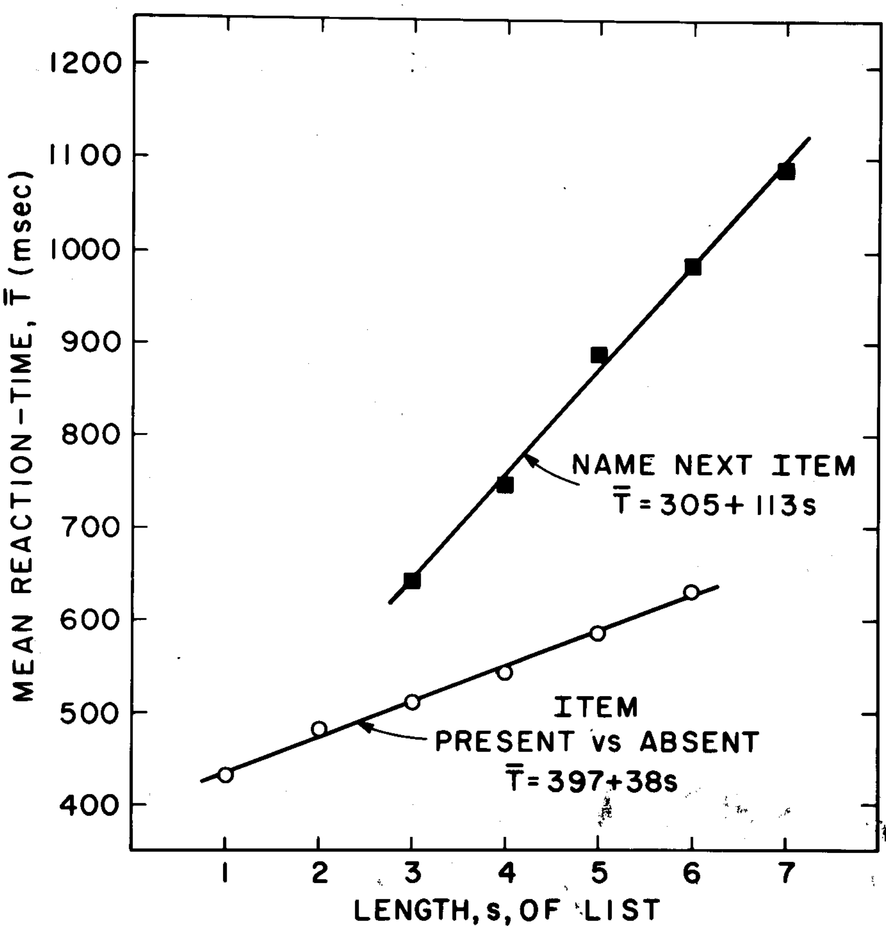

Fig. 3.

In both tasks, reaction-time increases linearly with list length, suggesting serial search processes. In the item-recognition task, the reaction-time increases by about 35 msec. for each item in the list. (It is also true that the latencies for positive and negative responses increase with list length at the same rate, and that the serial-position functions for positive responses are relatively flat.[3]) These findings and others have led to the conclusion that in the decision of whether or not a test item is present in a memorized list, the list is scanned exhaustively and at high speed. That is, all the items in the list are compared to the test item before positive responses as well as negatives, and at a rate of about 30 comparisons per second. Let us call this process <u>scanning for presence</u>.

In the context-recall task, the reaction-time increases by about 120 msec. for each item in the list. (It is also true that for lists of a given length, the reaction-time tends to increase with serial position. That is, there is a pure primacy effect.[4]) These findings and others have led to the following theory. In retrieval of contextual information the test item must first be located in the memorized list. This is achieved by a self-terminating process of <u>scanning to locate</u>: the test item is compared successively to the items in memory, until a match occurs, which ends the search. When the next item is to be named, the search is followed by a <u>shift</u> from test item to adjacent response item. On the average, only half of the items in the list are scanned before a match occurs, so that the scanning time per item is twice the slope of the reaction-time function.[5] Scanning to locate therefore has a rate of 4 or 5 items per second - about one sixth the rate of 30 items per second in scanning for presence.

In short, I explained the large difference between the estimated scanning rates in the two tasks by the idea that retrieval of contextual information requires that the location of the test item in the list be determined, and that locating an item in a memorized list involves a different and slower process from merely determining whether or not it is present.

The experiment I'll report here was done in order to check this explanation in several ways. One alternative account of the large effect of list length in the context-recall task is based on the idea that after a single presentation, a long list is not as well learned as a short list. For example, suppose that a list embodies a chain of associations, and that the naming of the next item involves the performance of one of the associations. If the associations in a longer list are weaker, reaction-time might then increase with list length, at least in part because of an increased associative latency. The possibility of such an effect is supported by the pattern of errors in the context-recall task: the percentage of errors in naming the next item increases markedly with list length, to about 25% for lists of seven digits.[6]

The first of the two tasks used in the new experiment was designed to look into the effects of level of learning of the list on reaction-time data from the context-recall procedure. I manipulated level of learning by varying the number of presentations of a list before presenting the test stimulus. In order to support the simple scanning interpretation of the data, one would have to find that the pattern of reaction-times was unchanged by this manipulation. As I will show you, this is in fact what was found.

The second task was constructed in order to test two other possible sources for the differences between the item-recognition and context-recall procedures. In the item-recognition procedure, the number of possible test stimuli does not vary with the length of the list, and neither does the number of alternative responses, which is always two. On the other hand, in the context-recall procedure, sizes of the set of possible test stimuli and the set of alternative responses both increase with list length. Since the number of stimulus-response alternatives is known to influence choice-reaction time, it would not be surprising if this contributed to the rapid growth of reaction time with list length in the context-recall procedure. A second difference between the procedures is that one involves recognition and the other recall.

These potential alternatives could be rejected if the same slow process of scanning to locate was shown to occur in a task where contextual information was retrieved from lists of varied length, but where the retrieval was indexed by a binary recognition response. The second task, which I will call a <u>context-recognition task</u>, was designed with these aims in mind. As I will show you, context recognition does seem to involve the same scanning process as context recall, confirming the idea of scanning to locate, and eliminating these alternative possibilities.

What I propose to do now is describe for each task the procedure and results, and then compare results from the two tasks. The same six subjects served for three sessions in each task, half the subjects in one order, and half in the other. In both tasks subjects were rewarded for speed and penalized heavily for errors. I'll be showing you averaged data from the second and third session in each task. Reaction-time data will be shown for correct responses only.

3 Presentations

List — List — List — Test stimulus — Correct response

$X_1,\ldots,X_s$ — Recall — $X_1,\ldots,X_s$ — Recall — $X_1,\ldots,X_s$ — $X_t \xleftrightarrow[\text{RT}]{}$ "X_{t+1}"

2 Presentations

$X_1,\ldots,X_s$ — Recall — $X_1,\ldots,X_s$ — $X_t \xleftrightarrow[\text{RT}]{}$ "X_{t+1}"

1 Presentation

$X_1,\ldots,X_s$ — $X_t \xleftrightarrow[\text{RT}]{}$ "X_{t+1}"

Fig. 4.

Figure 4 shows the paradigm of the first task, which involved context recall after one, two, or three presentations of a list. On each trial a list of from three to seven different random digits was presented visually and serially, either once, twice, or three times, at a rate of two digits per second. Ordered recall was required after presentations other than the last. After the last presentation there was a one-second delay, a warning signal, and then a test stimulus, randomly selected from among all the digits in the list except the last. The correct response was the spoken name of the digit that followed the test stimulus in the list. A voice-operated relay was used to measure the reaction time - the time from the onset of the test stimulus to the occurrence of the vocal response. (For example, in the condition with two presentations, the list was first presented, and the subject then attempted to recall it. Then the list was presented again, followed by a warning, test-stimulus, and response.)

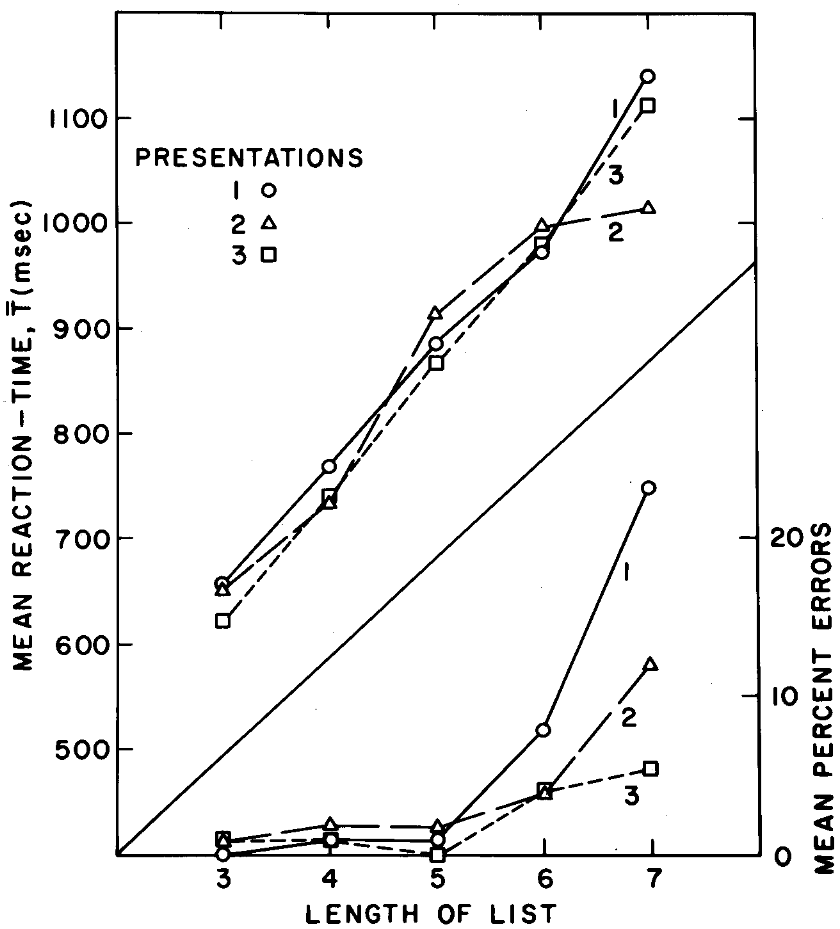

Fig. 5.

Data from this task are shown in Fig. 5. At the bottom of the figure is shown the percentage of errors in naming the next item as a function of list length, after one, two, and three presentations of the list. The added presentations reduce the average error rate by a factor of three. At the top of the figure is shown mean reaction-time as a function of list length for each of the three conditions. Despite the change in level of learning shown by the error data, the pattern of reaction times shows no systematic change with number of presentations. (As I have shown previously for this task, reaction time increases with serial position in a list of given length; this feature supports the inference of a self-terminating process.[7])

These data indicate that the effect of list length on mean reaction-time in the context-recall task is not an artifact of the relation between list length and level of learning. They show that the process of scanning to locate is independent of how well a list has been learned, within the limits provided by the experiment. In other experiments I have shown that the process of scanning for presence has a similar property (Sternberg, 1966).

How can changes in level of acquisition that influence the accuracy of responses have no effect on the retrieval process that generates these responses? One possibility is that number of presentations influences the correctness of the list that is retained, but that regardless of its correctness, the retained list is scanned in the same way.

Figure 6 shows the paradigm of the second task in the experiment, the contest-recognition task. On each trial the subject memorized a list of from three to six different random digits. The list was in fact presented twice, visually and serially at a rate of two digits per second, with ordered recall required after the first presentation. After

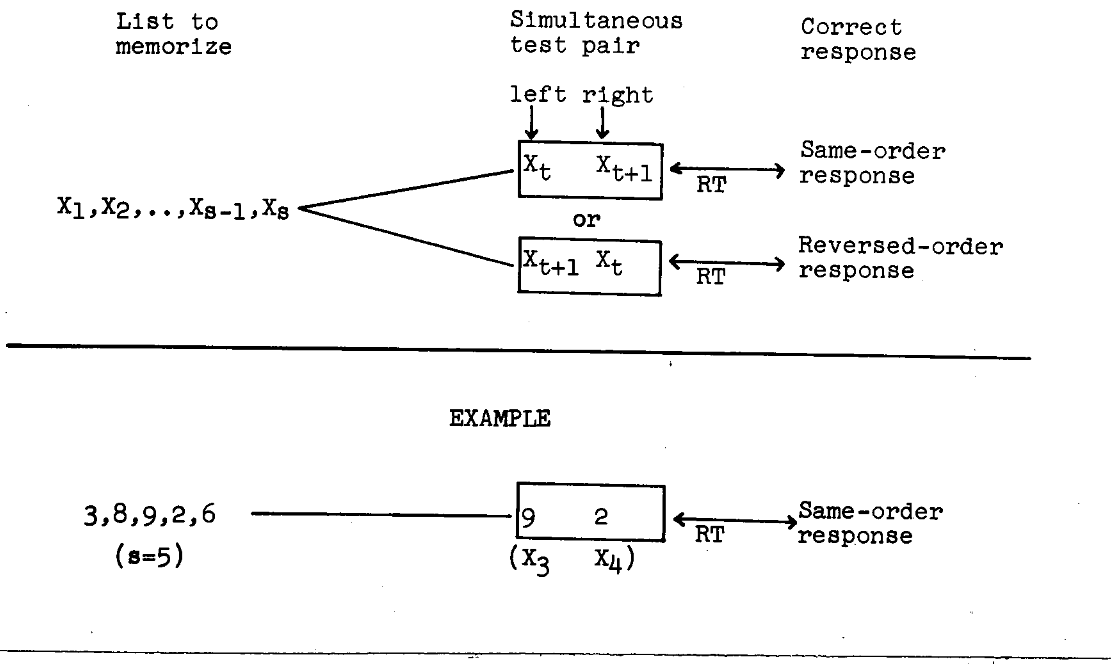

Fig. 6.

the second presentation, there was a one-second delay and a warning signal, and the subject then saw a test stimulus consisting of a pair of digits. The pair was chosen randomly from among the pairs of adjacent digits in the list. The subject's task was to decide whether the left-to-right order of the pair was the same as its temporal order in the list, or reversed. He made his binary response by pulling one of two levers. For example, if the memorized list was 3, 8, 9, 2, 6, and the test stimulus contained 9 and 2, with 9 on the left, the correct response would be the same-order response.

Using this task appeared to be somewhat risky, since there seem to be a variety of strategies open to the subject. My notion was that before its order could be tested, the pair might have to be located in the list by means of a scanning process. This process would be revealed by the relation between reaction-time and the length of the list. Suppose the scanning theory for the context-recall task is correct. Suppose further that the test pair in the context-recognition task is located in the list by scanning for the location of one of its members. One would then expect that mean reaction-time in the recognition task would increase linearly with list length for both kinds of response, and that the rate of increase would be the same as in the context recall task.

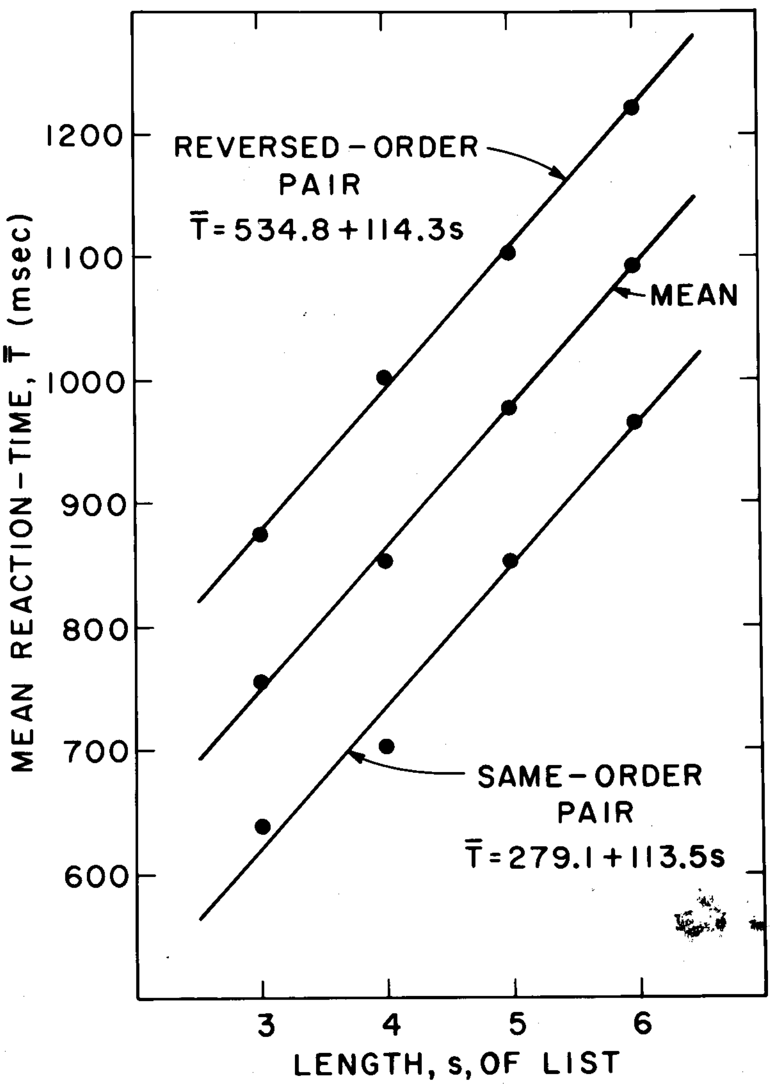

Fig. 7.

Figure 7 shows the relevant data. For each list length, reaction-times have been averaged over the possible serial positions of the test pair. The upper points show the latencies of reversed-order responses, and the lower points show the latencies of same-order responses, both as a function of list length. The middle points show the means. Latencies of both kinds of response increase linearly with list length, supporting the notion that in this task, also, performance involves a scanning process. For both responses the slope of the fitted line is 114 msec. per item. The equality of slopes is consistent with the idea that both responses depend on first locating one of the members of the pair in the list. (For all subjects, reaction-time increased with the serial position of the pair in the list, suggesting that the scanning process is self-terminating in this task also.[8]) Although equal in slope, the reaction-time functions for the two kinds of response differ by about 250 msec. in intercept. There are several ways in which one might account for this difference, but I won't discuss them now.

Let us turn now to the hypothesis that the same process, of <u>scanning to locate</u>, underlies performance in both the context recall and context recognition tasks. The strongest evidence for this hypothesis is shown in Fig. 8, where the reaction-time functions for the two tasks are compared. Mean reaction-time is plotted as a function of list length. The bottom set of points are there for reference, and come from an earlier item-recognition experiment (Sternberg, 1966, Exp. 1). The two other sets of points are from the new experiment.

The upper points are the averaged reaction-times that you have just seen for same-order and reversed-order

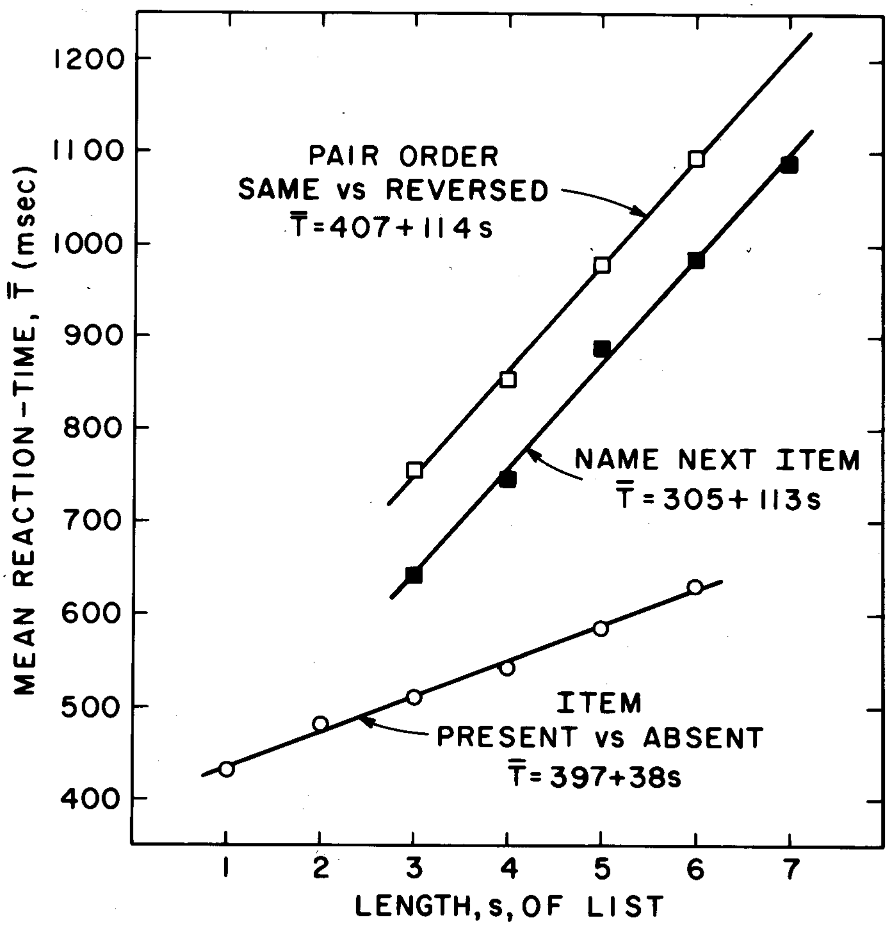

Fig. 8.

responses in the context-recognition task. The slope of the fitted line is 114 msec. per item. The middle points were obtained from the context-recall task by averaging the reaction-times from the conditions with one, two, and three presentations of the list. The slope of the fitted line here is 113 msec. per item.

(It was because earlier work had shown stable individual differences in scanning rate that both tasks in the present experiment were studied within subjects. Among the six subjects here, for example, slopes ranged from about 70 msec. per item to about 200 msec. per item. If the same scanning process is involved in both tasks, one would expect these individual differences to be maintained from one task to the other, so that the agreement between slopes derived from the group data should also be revealed for individual subjects. This was the case: the product-moment correlation over subjects of the slopes from the two tasks was .81.)

The difference between the intercepts for the two tasks probably results from a combination of effects on perceptual and response stages. The important point is that the stage between stimulus and response that involves a scanning process appears not to have been influenced by the change from context recall to context recognition.[9]

Taken together, these findings reinforce the explanation I mentioned earlier for the differences between performance in term recognition and context recall. The difference does not seem to depend on a relation between list length and the degree of learning of component associations. It does not depend on changes with list length in the number of stimulus and response alternatives. And it does not depend on a difference between recognition and recall.[10] Instead, it seems to depend on the fact that in the retrieval of contextual information the location of the test stimulus in the memorized list must be determined, whereas in merely deciding whether an item is present in a list, this is not necessary. And locating an item in a memorized list involves a very different search process from deciding whether or not it is present.

FOOTNOTES

1. Presented at the annual meeting of the Eastern Psychological Association, April 1969, Philadelphia, Pa. I thank Ben Barkow and Barbara Nasto for laboratory assistance. This research was briefly described in Sternberg, 1968.
2. See also Appendix 1.
3. This last feature may be sensitive to experimental conditions; see Corballis, 1967; Morin, DeRosa, and Stultz, 1967; and Morin, DeRosa, and Ulm, 1967.
4. See Appendices 1 and 2.
5. This statement is only approximate. Assume equiprobable placement of the test item among the first s-1 items in a list of length s. If scanning starts at the first item, the mean number of items scanned before a match is $(s-2)/2$. If scanning starts at a random item, and the last item is included among those scanned, the mean number scanned before a match is $(s-1)/2$. In both cases an increase in list length by Δs items results in an increase by $\Delta s/2$ in the mean number of items scanned.
6. See Appendix 1.
7. See Appendix 2.
8. See Appendix 3.
9. See Sternberg, 1969 for a detailed discussion of the use of additive factors, such as list length and task in this case, for inferring the existence and properties of processing stages.
10. A fourth possibility, also eliminated by these findings, is that because the context-recall task requires a name to be produced as a response, the memory that is scanned involves a representation, for each item in the list, that is different from the item representation in the recognition tasks. The relative slowness of the process

could then be explained in terms of a difference in the kind of representations scanned, rather than the kind of information sought.

But a fifth alternative, which leads to the same explanation of the relative slowness of scanning to locate, is not eliminated by the results: this conjecture, offered by Norman Guttman, is that the kind of memory representations that are capable of carrying order or position information are different (perhaps because they involve covert speech) from those required to carry item information only. (Because subjects in the item-recognition task can produce accurate ordered recall of the list after their recognition response [Sternberg, 1966], this conjecture requires that they be able to maintain both representations of the list simultaneously.)

APPENDIX 1

Results from six subjects in an earlier study using the context-recall procedure (Sternberg, 1967). A. Effect of list length, S, on accuracy of response and $\overline{RT}$. Percent errors (bars), $\overline{RT}$ of correct responses (open circles, about 400 observations each) with estimates of $\pm\sigma$ and least-squares line, and $\overline{RT}$ of all responses (filled circles). B. Relation between $\overline{RT}$ of correct responses and serial position of the test item in lists of five lengths.

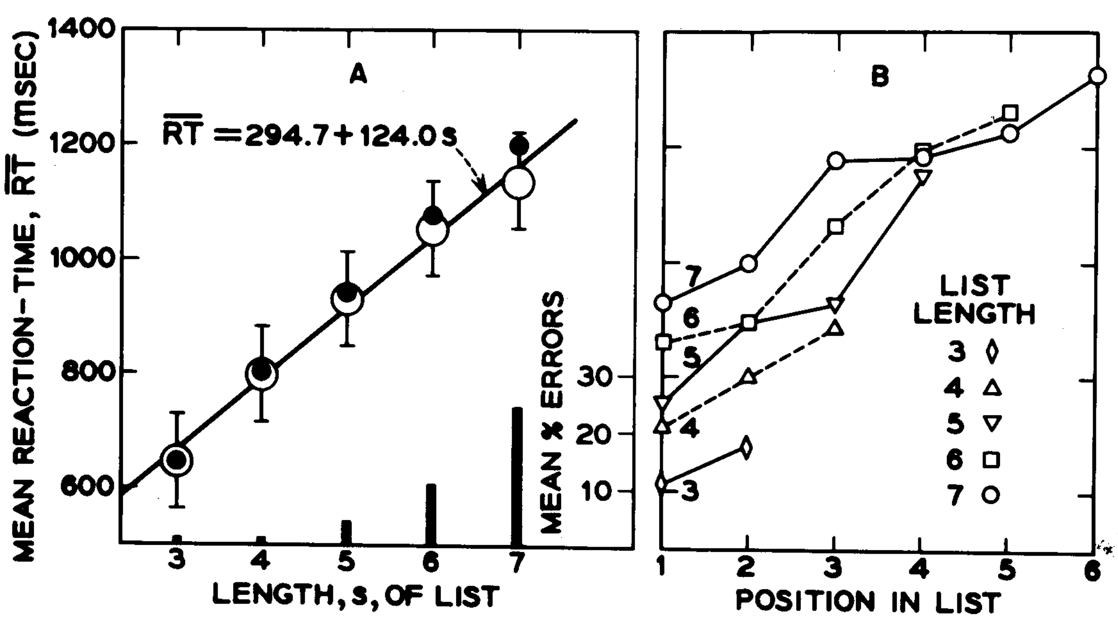

Fig. 9.

APPENDIX 2

Relation between $\overline{RT}$ of correct responses and serial position of the test item in the context-recall task of the present experiment.

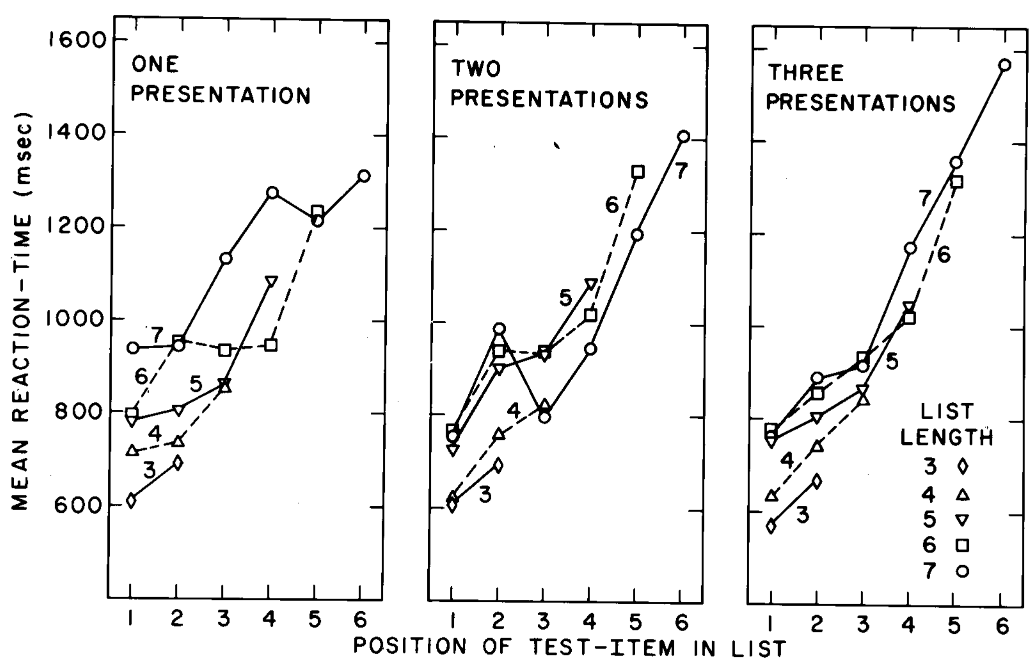

Fig. 10.

APPENDIX 3

Relation between $\overline{RT}$ of correct responses and serial position of the test pair in the context-recognition task of the present experiment. Curves for same-order and reversed-order pairs are similar in shape and have been averaged.

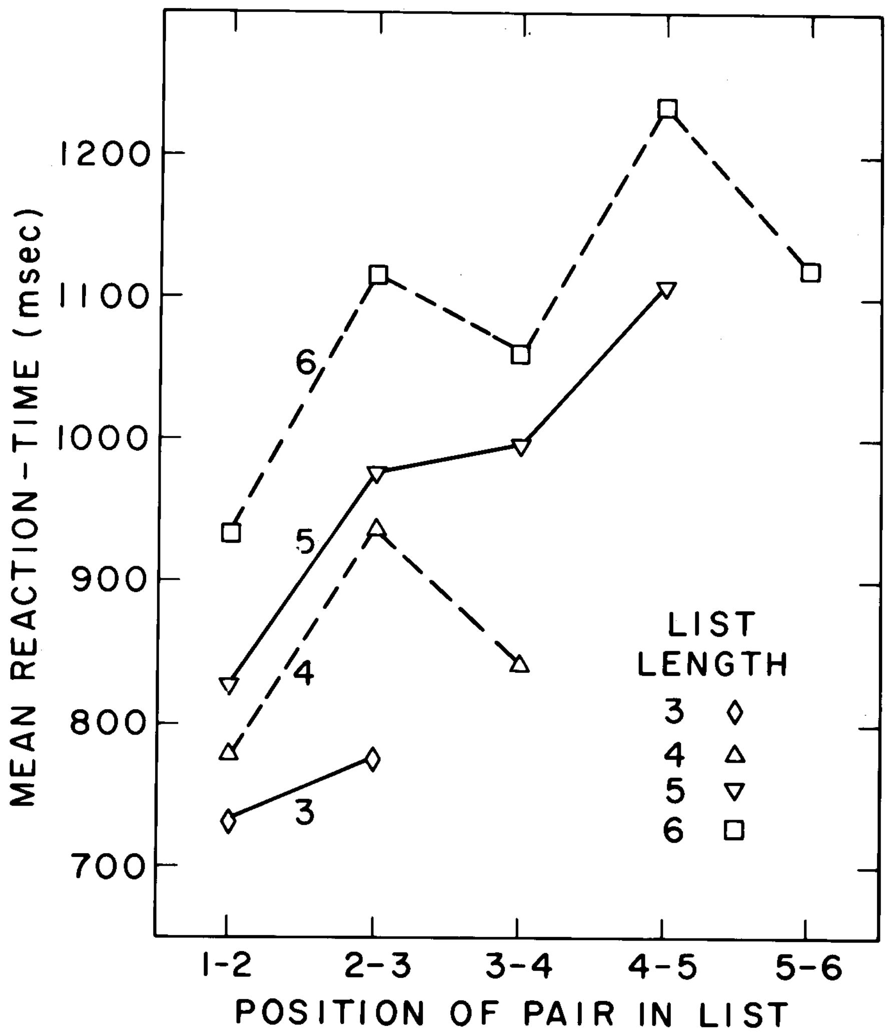

Fig. 11.

REFERENCES

Corballis, M. C. Serial order in recognition and recall. J. exp. Psychol., 1967, 74, 99-105.

Morin, R. E., DeRosa, D. V., and Stultz, V. Recognition memory and reaction time. Acta Psychol., 1967, 27, 298-305.

Morin, R. E., DeRosa, D. V., and Ulm, R. Short-term recognition memory for spatially isolated items. Psychon. Sci., 1967, 9, 617-618.

Sternberg, S. High-speed scanning in human memory. Science, 1966, 153, 652-654.

Sternberg, S. Retrieval of contextual information from memory. Psychon. Sci., 1967, 8, 55-6.

Sternberg, S. Inferring the organization of cognitive events from reaction-time: Some scanning processes in active memory. Paper presented at the Symposium on Research in Cognitive Psychology, City University of New York, June 1968. To be published.

Sternberg, S. The discovery of processing stages: Extensions of Donders' method. Acta Psychologica[Attention and Performance II (W. G. Koster, ed.)], 1969, 30, 276-315, (In Press).