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Sources of Intratrial Interference in Immediate Recall of Paired Associates[1]

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A typical verbal-learning trial consists of two distinct phases, presentation of the material and attempted recall, or input and output. While many different patterns of input and output sequences can be and have been used in experiments, the two phases are necessarily separated in time. A reasonably small unit of material, such as an individual item, can practically always be recalled immediately after its presentation (Murdock, 1961a, b; Peterson, Saltzman, Hillner, and Land, 1962). In this sense the item is always "learned" when it is presented. If it cannot be recalled following a retention interval, however short, it must have been "forgotten" during that interval.

This paper is concerned with intratrial forgetting of individual list items, i.e., with forgetting as it occurs within a single learning trial. Intratrial retention intervals of individual items are filled with inputs and outputs of other items. These two kinds of intervening activities can be regarded as two sources of intratrial interference responsible for forgetting of the critical item.

If a list of, say, ten items A, B, C, . . . , I, J, is presented to *S* in this order and at a fixed rate, and *S* is then asked to recall these items in the same order and at the same rate, the length of the intratrial retention interval is identical for all items, but the particular combination of intervening inputs and outputs varies for items in different serial positions. For example, for the first list-item, A, presentation and recall are separated by nine additional inputs; for the second item, B, they are separated by eight additional inputs and one output, and so on, until for the last item, J, they are separated by nine outputs. If we assume that inputs and outputs represent two different sources of intratrial interference having different effects on the recall of an item, then it is necessary to analyze them separately and to examine their joint effects.

Output interference has been studied for tachistoscopically presented materials by Sperling (1960) and by Averbach and Coriell (1961). Their findings show that some of the stimulus information available to the *S* from the input becomes unavailable as a consequence of temporally extended output. Experimental analyses of response interference in memory tasks involving sequentially presented materials have been reported by Kay and Poulton (1951), Brown (1954), Anderson (1960), and Mackworth (1962). Their findings have similarly shown that the act of recall of parts of the input material interferes with the recall of other parts. Experiments by Peterson and his associates (Peterson and Peterson, 1959; Peterson *et al.*, 1962) and by Murdock (1961b) on short-term retention of nominally defined individual items also have demonstrated rapid deterioration of recall following increasing amounts of intervening activity.

Input interference has been assessed separately from output interference in intratrial

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retention, for geometric forms by Gibson and Raffel (1936) and for paired associates by Murdock (1961a). After presenting to *S* a list of paired associates, Murdock had *S* recall just a single item. By varying the length of the list and the serial position in the list of the item to be recalled, Murdock could observe the effect of the number of proactive and retroactive items on the recall of the critical item under conditions where no output interference was present. Input interference was clearly demonstrated: probability of recall of the critical item was an inverse function of the number of items intervening between input and output.

No experiments have been reported in which the combined effects of these two sources of interference, input and output, have been systematically explored. The present paper describes a method that can be used to separate the two sources and reports the findings of an experiment in which their concurrent effects on intratrial retention of individual items were investigated.

METHOD

The method used in this experiment involved the recall method of paired-associate learning (Battig and Brackett, 1961). Pairs of items are presented in a sequence for study by *S*, and then stimulus items alone are presented in a sequence, either identical with or different from the input sequence (e.g., Newman and Saltz, 1962). When this method is used, the amount of input and output interference can be specified in terms of the number of inputs and outputs in the intratrial retention-interval for a given item. Number of intervening inputs and outputs can be varied systematically by manipulating the relation between input and output sequences.

Lists of ten paired associates were used throughout this experiment. Ten different output sequences were constructed such that an *S* receiving one trial on each of ten different lists would contribute data to all 100 cells of a 10 by 10 serial position (SP) matrix. The rows of such a matrix represent 10 successive serial positions in the input lists; the columns stand for 10 successive serial positions in the output sequences. The cells of the matrix thus represent various combinations of input and output positions, and recall data entered into the matrix provide estimates of input interference, output interference, and their interaction, if any.

Materials

Twenty different lists of 10 paired associates were used in the experiment. All lists had in common two features: stimulus items were always single digits between 0 and 9, and response items within a given list were always common nouns belonging to the same conceptual category. The categories were: animals, birds, fabrics, flowers, fruits, means of transportation, metals, professions, trees, and vegetables. The ten most common words of six letters or less for each of these ten categories, as tabulated by Cohen, Bousfield, and Whitmarsh (1957) were twice paired randomly with digits from 0 to 9 to yield the 20 lists.

Pairs of items were printed in black letters on white 3 × 5 in. cards. Similar cards containing only the stimulus items were also prepared.

Input and Output Sequences

The input sequence of a list can be specified by listing the order of stimulus items. Two different conditions of input sequence were used in the experiment. Under the first condition, called ordered input, the paired associates were presented in the ascending order of stimulus items, from 0 to 9, in all 20 lists. Under the second condition, called random input, the order of pairs was determined randomly for each of the 20 lists.

Ten different output sequences were generated to provide for recall of each of the items in ten different input positions in all ten positions of the output sequence. The output sequences can be described by specifying the order in which items, designated by their positions in the input sequence, are presented for recall. The ten output sequences are shown in Table 1. The columns correspond to the ten output sequences, the rows represent successive positions in these sequences, and the entries in the table give the ordinal positions of items in the input sequence. Thus, the first item presented for recall in Output Sequence No. 1 was the item that appeared first in the input sequence; the seventh item presented for recall in Output Sequence No. 9 was the item that appeared in the eighth position in the input sequence; and so on.

If the serial position in the output sequence is designated by *i*, and the number of output sequence is designated by *j*, then the entry in the *i*th row and *j*th column (N_{ij}) can be found by the simple formula: $N_{ij} = i \times j$ in modulus $L+1$, where L stands for the length of the list. The formula can always be used if $L+1$ is a prime number and if $j \leqslant L$.

Notice that each row is identical with its corresponding column. Thus, the two halves of the table, divided along either rows or columns, are symmetrical. Output Sequence No. 10, for instance, rep-

TABLE 1
TEN DIFFERENT OUTPUT SEQUENCES USED IN THE EXPERIMENT
(Entries in the table represent ordinal positions of items in the input sequence. See text for details.)

Output position	Ordinal number of output sequence									
	1	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	6	7	8	9	10
2	2	4	6	8	10	1	3	5	7	9
3	3	6	9	1	4	7	10	2	5	8
4	4	8	1	5	9	2	6	10	3	7
5	5	10	4	9	3	8	2	7	1	6
6	6	1	7	2	8	3	9	4	10	5
7	7	3	10	6	2	9	5	1	8	4
8	8	5	2	10	7	4	1	9	6	3
9	9	7	5	3	1	10	8	6	4	2
10	10	9	8	7	6	5	4	3	2	1

resents the reverse order of Output Sequence No. 1, which itself constitutes the same order as the input sequence. It is not necessary, of course, to make the first output sequence identical with the input sequence. Once a particular output sequence is adopted as the first one, however, the table defines other sequences in terms of the first one. Furthermore, since the output sequences are specified in terms of input positions, rather than specific items in the input, any given set of ten output sequences can be used in conjunction with any particular input sequence.

Subjects and Procedure

The *S*s were 50 summer school students, 24 men and 26 women, enrolled in various psychology courses at the University of Toronto. Each *S* served in two experimental sessions, held either 48 or 72 hours apart. In one of the sessions, the *S* learned ten lists under the condition of ordered input, and in the other he learned ten lists under the condition of random input. The ten lists learned in a given session represented one set of random pairings of stimulus digits with words from the ten conceptual categories (Set A), while the ten lists in the other session represented the second set (Set B). Twenty-five *S*s (Group 1) received the ordered input in the first session and the random input in the second, while for the other 25 *S*s the conditions were reversed. Twelve *S*s in Group 1 and 13 *S*s in Group 2 were given lists in Set A in their first session, the remainder, lists in Set B. Each *S* received the alternate set in the second session.

The order of lists in a given set administered to *S*s was varied systematically across *S*s, such that each list was presented equally often in each position in the series of ten lists. For each *S*, different lists were associated with different output sequences according to a table of random numbers.

Cards containing digit-word pairs were presented for learning by means of a manually operated card holder, as were cards containing stimulus items only. The card holder was attached to the side of a plywood screen that separated the *E* from the *S*. Cards were stacked in the holder in a predetermined order and were exposed to *S* by successive removals of cards from the top of the stack. The first card was always a blank, and its removal constituted the beginning of the trial. A blank card was also inserted between the first ten (S-R pairs) and the second ten (S-) cards.

Cards were exposed at a constant rate of approximately 3 sec. per card both during the input and output phase. Apart from the blank card between the input and output items that was handled at the same rate as all other cards there was no interval between presentation of items. Since presentation of pairs and of stimulus items alone proceeded at the same rate, length of the retention interval covaried systematically with the number of intervening inputs and outputs.

Prior to each experimental session, *S*s were given three practice trials on a paired-associate task in which the stimulus and response items were uncommon nouns and adjectives bearing no apparent relation to the experimental materials. These were administered not only to acquaint the *S* with the general nature of the task but also to reduce the initial warm-up and learning-to-learn effects.

The *S*s were informed at the beginning of the experimental session that they would be presented with ten lists and that each list would involve single digits as stimulus items and common nouns from various conceptual categories as response items. Before each new list was presented, *S*s were told what the category of response words was. Categorical lists were used in order to minimize interlist intrusions, common nouns were adopted to minimize response learning (Underwood and Schulz, 1960). The *S*s pronounced both the stimulus and response items when these were presented, pronounced the stimulus items in the output phase, and attempted to give correct responses whenever possible. They were told that guessing was permissible and that they could make the same response more than once in the recall of a given list.

The *S*s' oral responses during the output phase were all recorded by *E*, provided that they were made before the next stimulus item was exposed. Late recalls were recorded as omissions. The *S*s were warned against making delayed responses and the warning was repeated at the conclusion of any trial when they had done so. After each trial, *S* was also told how many items he had recalled correctly.

RESULTS

There were four modes of responding available to *S* in this experiment: correct recall; intralist intrusion, i.e., response appropriate to the list, but not to the stimulus item; extralist intrusion, i.e., response not contained in the list; and response omission, or failure to respond within the specified interval.

The total number of all these responses was 10,000 (50 *S*s × 2 conditions × 10 lists × 10 items). As there were only ten instances of extralist intrusions among all responses, only the other three response categories were considered in analyzing the data.

The main interest in this experiment lies in the distributions of responses in the serial position (SP) matrices. SP matrices, based on the three types of responses, were constructed separately for both groups of *S*s and for the two input conditions. Inspection of the matrices revealed that the distributions of responses for the two groups were rather similar within a given input condition, that is, they were not greatly affected by whether lists were learned in the first or second experimental session. Product-moment correlation between frequencies of correct response in 100 cells of the SP matrices of the two groups of *S*s was +.94 for lists involving ordered input sequences, and +.92 for random lists. The data, therefore, were combined for all *S*s under a given input condition. The distributions of responses in the SP matrices were quite different for ordered and random inputs, however, and for this reason the two conditions will be considered separately.

Ordered Input

Table 2 represents the SP matrix based on correct responses for ordered lists. Rows stand for input positions and columns for output positions of items. The number in any given cell is a percentage and indicates the relative frequency of correct recalls for that particular combination of input and output position. The SP matrix in Table 2, as all other recall matrices to be considered later, is based on data from all 50 *S*s. Since each *S* made just one response under each combination of input and output position, the *n* correct responses in any cell—obtainable by dividing the cell entry in Table 2 by 2—were given by *n* different *S*s. There were 20 different lists in the experiment and hence 20 different items occupying a given serial position in the input sequence. The frequency of correct responses in any cell, therefore, could be based on a variety of combinations of the 20 items. Since output sequences were assigned randomly to input lists, all 20 items, however, need not be represented in all cells.

No statistical analyses were performed on the data in any SP matrices. The general effects of input and output position can be discerned by inspection of the data, and conclusions can be drawn on the basis of orderly trends in the data. Statistical significance of effects associated with input position, output position, and their interaction seemed to be beyond any reasonable doubt.

The combined effects of input and output positions on recall are seen best when the data in the SP matrix are presented graphically. Rather than attempt the simultaneous comparison of ten curves, each based on ten

TABLE 2
PERCENTAGE OF CORRECT RESPONSES AS A FUNCTION OF INPUT AND OUTPUT POSITIONS FOR ORDERED INPUT LISTS

Input position	Output position 1	2	3	4	5	6	7	8	9	10	Mean
1	76	78	80	80	74	76	82	80	74	88	78.8
2	52	54	42	48	56	48	38	58	48	36	48.0
3	18	30	42	34	18	30	40	28	28	28	29.6
4	22	36	26	32	30	36	28	22	22	32	28.6
5	24	32	46	34	32	26	28	30	22	32	30.6
6	44	42	14	44	30	28	16	32	38	26	31.4
7	48	34	32	48	26	24	42	28	30	32	34.4
8	50	44	50	34	36	38	38	46	32	24	39.2
9	76	70	40	44	44	42	38	32	48	38	47.2
10	100	84	66	52	50	46	44	40	38	42	56.2
Mean	51.0	50.4	43.8	45.0	39.6	39.4	39.4	39.6	38.0	37.8	42.40

data points, some of the highlights of the findings can be illustrated by combining data for successive pairs of input and output positions and presenting selected curves based on such combined data. This procedure removes some of the more striking effects associated with recall of items in extreme positions of input and output sequence—such as the fact that the last input item is always recalled when it is in the first output position—but it makes the general trends clear.

Figure 1 shows the effect of input position on the probability of correct recall with output position as the parameter. The general shape of these curves gives evidence of the typical serial position effects. The primacy effect is quite pronounced and approximately equal for all output positions. Recency effects are also present, but their extent varies for different output positions. The recency effect is greater than the primacy effect for items early in the output sequence, and smaller than the primacy effect for items in the middle and final positions in the output sequence.

The striking interaction between input and output position suggested by these curves can be expressed differently, as shown in Fig. 2. In Fig. 2, probability of recall is plotted against output position, with input position as the parameter. It appears that items learned early in the input sequence are relatively impervious to output interference. Whether such items are recalled early or late in the output sequence seems to make little difference to their availability.

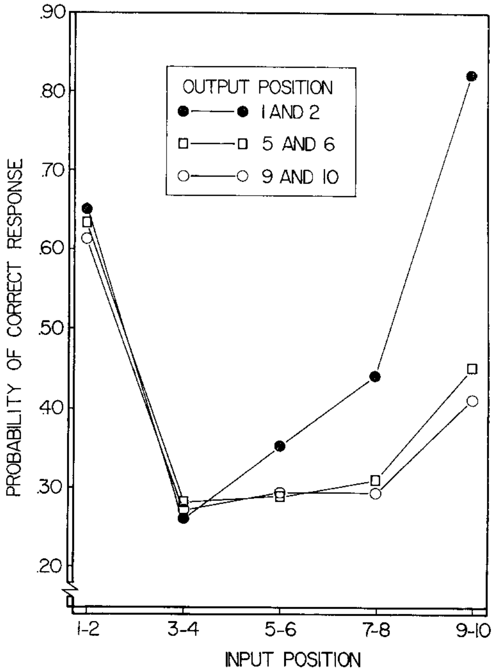

FIG. 1. Probability of recall of individual items as a function of input position, with output position as parameter, for ordered input lists.

Items in the middle positions in the input sequence, shown by the lowest curve in Fig. 2, are also relatively little affected by output interference, although there is a trend toward lower recall with increasing position in the output sequence. The effects of output interference, however, are quite clear for late items in the input sequence. The greater the number of attempted recalls that intervene between the input and output of such items, the smaller is their availability at the time of recall. The curve expressing this relation is negatively accelerated, with most of the interference effects attributable to the first five or six outputs.

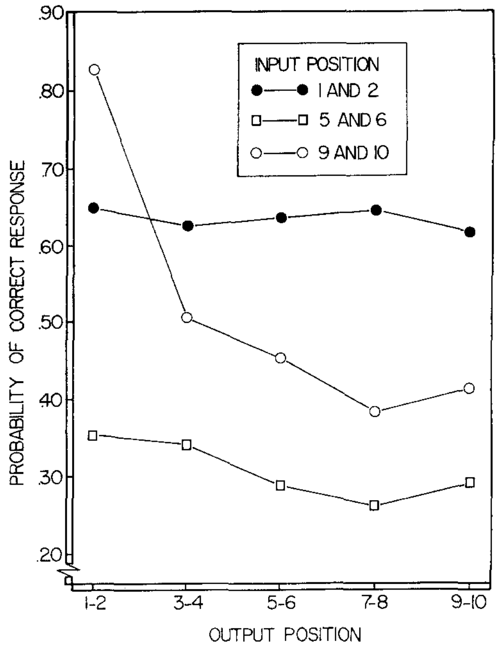

FIG. 2. Probability of recall of individual items as a function of output position, with input position as parameter, for ordered input lists.

Table 3 presents the SP matrix for response omissions in ordered lists. In general, these data reflect the same kind of interaction between input and output position as is evident from data on correct responses. For instance, failure to respond to the stimulus item presented in the first position of the input sequence is considerably lower than to stimulus items of other pairs and it is relatively little affected by the output position, but failure to respond to stimulus items presented late in the input sequence increases systematically with the number of intervening outputs. However, exceptions to the general rule that correct responses and omissions are complementary should also be noticed. For instance, when marginal totals in Table 2 are added to corresponding marginal totals in Table 3, the sums are not constant. This variability is attributable to the fact that incorrect intralist responses also depend on input and output positions of items.

Data for intralist intrusions are omitted in

TABLE 3
PERCENTAGE OF RESPONSE OMISSIONS AS A FUNCTION OF INPUT AND OUTPUT POSITIONS FOR ORDERED INPUT LISTS

Input position	Output positions 1	2	3	4	5	6	7	8	9	10	Mean
1	16	18	10	14	18	12	16	14	20	8	14.6
2	24	26	30	40	28	24	44	36	42	42	33.6
3	44	26	34	30	48	50	38	38	40	36	38.4
4	46	36	40	40	34	46	38	62	52	40	43.4
5	40	26	30	36	42	50	42	44	56	42	40.8
6	28	36	48	36	38	52	56	48	46	50	43.8
7	28	28	34	24	44	46	52	50	44	40	39.0
8	22	26	20	36	34	32	48	38	54	58	36.8
9	10	12	30	34	40	48	40	40	34	50	33.8
10	0	0	22	28	28	30	42	42	50	50	29.2
Mean	25.8	23.4	29.8	31.8	35.4	39.0	41.6	41.2	43.8	41.6	35.34

TABLE 4
PERCENTAGE OF CORRECT RESPONSES AS A FUNCTION OF INPUT AND OUTPUT POSITIONS FOR RANDOM INPUT LISTS

Input position	Output position										Mean
	1	2	3	4	5	6	7	8	9	10	
1	50	46	58	50	50	34	56	60	48	48	50.0
2	28	44	24	38	48	34	50	34	50	40	39.0
3	46	42	48	36	44	44	34	30	48	40	41.2
4	28	36	28	36	44	30	48	28	28	38	34.4
5	40	32	44	42	50	44	44	34	44	40	41.4
6	44	36	28	24	36	28	34	42	44	36	35.2
7	46	44	40	54	32	40	46	52	36	40	43.0
8	52	48	48	34	42	38	48	34	40	38	42.2
9	70	74	50	54	42	28	34	30	42	38	46.2
10	96	66	48	36	58	32	48	52	34	54	52.4
Mean	50.0	46.8	41.6	40.4	44.6	35.2	44.2	39.6	41.4	41.2	42.50

this report, since the SP matrix based on these errors, for all practical purposes, is completely redundant with those based on correct responses and omissions.

Random Input

The SP matrix for correctly recalled responses under the conditions of random input sequences is presented in Table 4. Even a casual inspection of these data reveals some rather striking differences between ordered and random lists. While the overall means, as shown in Tables 2 and 4, are practically identical in both cases (42.4 and 42.5 for ordered and random inputs, respectively), there are some obvious differences in the patterning of data in the SP matrices.

Consider, for instance, the probability of recall of the first input item. Under the condition of ordered input, the mean percentage of recall of the first input item, averaged over all output positions, is 78.8. The same percentage under the condition of random input is 50.0. The mean percentage of correct recall of the second input item is 48.0 for ordered lists, and 39.0 for random lists. For the items in the middle input positions, from 3 to 8, however, recall is somewhat higher under random input conditions than under ordered input conditions.

These and some other differences can be seen in summary form in Figs. 3 and 4. In Fig. 3 probability of correct recall for items in random lists is plotted against input position, with output position as the parameter. Fig. 3 is to be compared with Fig. 1, where the same curves are shown for ordered inputs. By a considerable stretch of imagination it is perhaps possible to say that the curves in Fig. 3 are attenuated counterparts of those in Fig. 1, but the only very obvious feature that the two sets of data seem to have in common is the pronounced recency effect when recall is measured in absence of output interference. Primacy effects are much smaller for all output positions.

When the correct recall data are plotted against output position, with input position as the parameter, as in Fig. 4, the differences between ordered lists and random lists are equally obvious. The curves in Fig. 4 and those in Fig. 2, showing the same plot for random and ordered inputs, seem to have only one feature in common. This is the relatively large output interference effect in the case of items in late input positions. There seems to be a small increase in probability of recall of items in early input positions with output position (output facilitation?), while output seems to have no systematic effect on recall of items in middle input positions. Inspection of the more detailed break-

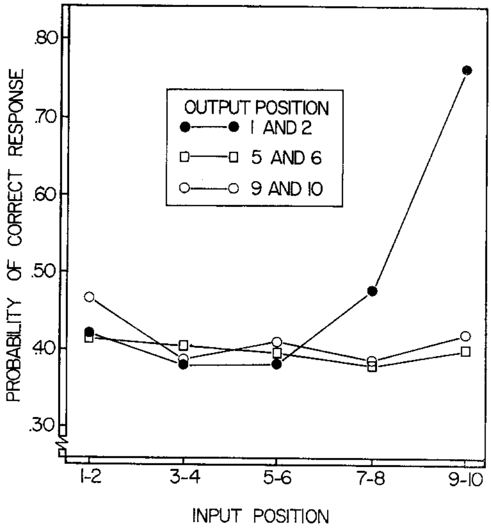

FIG. 3. Probability of recall of individual items as a function of input position, with output position as parameter, for random input lists.

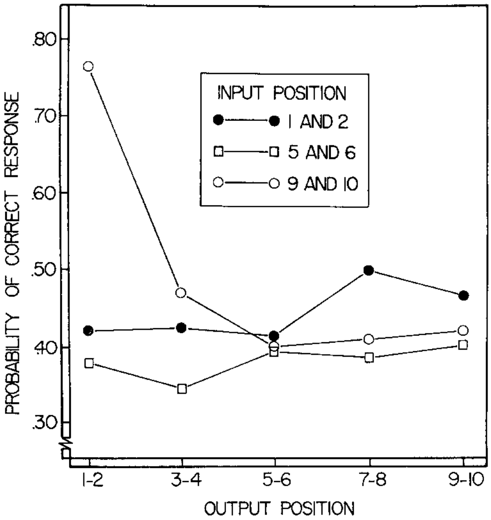

FIG. 4. Probability of recall of individual items as a function of output position, with input position as parameter, for random input lists.

down of the data in Table 5, however, fails to offer much support for the "output facilitation" of early input items, and, for the time being at least, it seems more reasonable to attribute the apparent rise of the first and second input position curve in Fig. 4 to uncontrolled sources of variance.

Table 5 represents the SP matrix for omissions under the condition of random input sequences. The mean percentage of omissions for random lists, 36.34, is approximately the same as for ordered lists, 35.34. The distribution of omissions in the matrix in Table 5 to some extent reflects differences between the two conditions that already have been pointed out in some detail in the context of probability of correct responses. Thus, the number of omissions tends to be greater in random lists (Table 5) than in ordered lists (Table 3) for early and late input items and smaller for middle input items, although the differences are quite small. Omissions tend to increase with output position under both ordered and random input conditions, and in both cases this is especially pronounced for items in late input positions.

The deviation from complete complementarity of correct responses and omissions for random lists also should be noted. For instance, omissions increase as a function of output position, when recall is averaged over all input positions, at a faster rate than correct responses decrease. This is accounted for by the fact that incorrect intralist responses also tend to decrease over successive output positions. The matrix of these error data can be derived from data on correct responses and omissions.

An Effective Strategy for Recalling Paired Associates

Although the findings of this experiment are somewhat different for the two main conditions under which data were gathered—ordered and random input sequences—there is one important finding in common to both. While output interference does not seem to operate on recall of early and middle input items, it has pronounced effects on the items late in the input sequence.

This observation suggests that an effective method for recalling lists of paired associates —perhaps even serial lists, if the same phenomenon holds under those conditions—

Table 5
Percentage of Response Omissions As a Function of Input and Output Positions for Random Input Lists

Input position	Output position										Mean
	1	2	3	4	5	6	7	8	9	10	
1	20	20	24	28	20	40	12	30	34	40	26.8
2	46	40	40	30	36	42	26	52	28	46	38.6
3	32	38	30	40	32	34	42	44	34	46	37.2
4	40	44	42	32	34	46	34	46	56	48	42.2
5	40	44	40	36	32	34	38	42	42	40	38.8
6	32	44	44	44	46	46	48	36	46	44	43.0
7	30	30	36	26	36	36	36	26	34	52	34.2
8	16	30	22	42	40	36	38	46	52	42	36.4
9	20	16	28	28	40	48	46	40	42	44	35.2
10	0	18	34	44	14	44	40	32	50	34	31.0
Mean	27.6	32.4	34.0	35.0	33.0	40.6	36.0	39.4	41.8	43.6	36.34

calls for testing the recall for pairs of items during the output phase in the order reverse to that in which they appear in the input sequence. The availability of early input items does not change materially during the whole output sequence, whereas that of late items does. It is important, therefore, to have *S* recall the late items first, before they succumb to the effects associated with attempted recall of other items.

Among the ten output sequences consistently used in this experiment there were two that provide a relevant comparison. Output Sequence No. 1 is the "forward" sequence that has often been used in experiments. Output Sequence No. 10, on the other hand, is the reverse of both the input sequence and of the Output Sequence No. 1. The data for lists in which the forward output order was used, are found in the main diagonal, from upper left to bottom right, of the SP matrix. The data for the reverse order are located along the secondary diagonal, from upper right to bottom left, of the matrix.

When these data are examined, they fully support the contention that recalling items in the reverse order constitutes a more effective strategy than recalling them in the standard order. The mean number of words recalled for the forward order was 4.42, and for the reverse oder, 5.16, under the conditions of ordered input sequences. The corresponding figures for random input sequences were 4.32 and 5.28, again demonstrating the superiority of the backward order. These differences were evaluated statistically by means of *t*-tests. The obtained *t*'s were 2.53 and 3.71 (both with 49 *df*) for ordered and random lists, respectively. Both are significant beyond .05 level.

That the advantage of recall of items in the reverse order is independent of strategies associated with learning, i.e., inputting, can be argued from the fact that in the present experiment *S*s did not know in advance of the presentation of each new list what the output sequence was going to be.

On the basis of the data considered earlier, it might be expected that the advantage of the reverse output order over the forward order lies mostly in the higher recall probability of late input items. That this is indeed the case can be seen from Fig. 5, in which have been plotted the serial position curves based on data from lists involving forward and reverse order for both ordered and random input conditions. While items from the first to the sixth input positions are recalled approximately equally well in both recall orders within a given condition of input sequence, the recall of items in later input positions, and particularly in the ninth and tenth position, is strikingly superior in reverse recall order.

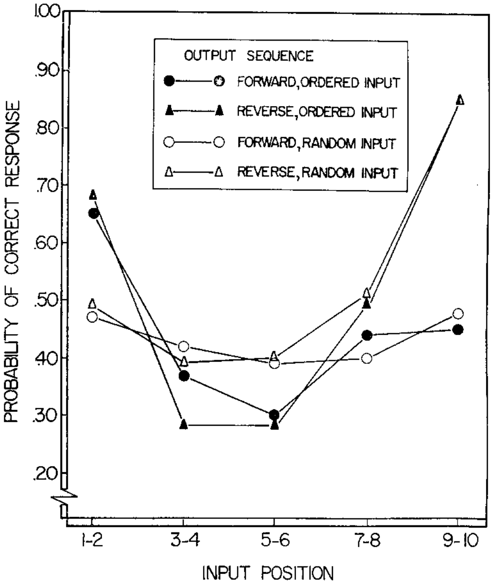

FIG. 5. Serial position curves for "forward" and "reverse" output sequences under conditions of ordered and random input sequences.

Whether the superiority of the stategy of reverse order recall is limited to just a single trial or whether it would hold up, or even increase, under conditions where many learning trials are given, is clearly a problem for future research.

DISCUSSION

We shall briefly discuss the method and the design used, the notion of input and output interference, relevance of the findings to the literature on serial position curves, and some implications of the experiment for the problem of whether associations are learned on a single trial or incrementally.

Method and Design

The method that was used in this experiment seems to be useful in that it has provided new information about intratrial retention of individual items in a list of paired associates. However, it is not free from shortcomings. First, no attempt was made in the present experiment to compare the effects of successful recall with those of unsuccessful attempts at recall of other list items upon retention of the critical item. Output was defined in terms of *attempted* recall, without regard to whether it resulted in correct response, incorrect response, or failure to respond. It is quite possible that the effects of different output events on retention of a given item are different. Second, the method used did not permit us to make a distinction between intervening activity on the one hand and passage of time and consequent decay of memory trace (Brown, 1958) on the other hand. It is clear, however, that findings of primacy effects and the observation that recall of early input items is unaffected by their position in the output sequence are not easily explained solely in terms of the concept of decay of the trace. Third, the method ignores proactive effects in learning and subsequent recall of single associations. Murdock (1961a) has shown that intratrial retention of single paired associates in absence of any output interference is influenced by the number of items preceding the critical item in the input list, and the importance of proactive effects in longer-term retention has been convincingly demonstrated by Underwood (1957). It is reasonable to assume that proactive effects, both from item to item within a list and from list to list, occurred in the present experiment, but they cannot be readily analyzed.

The design that we used ignores certain interactions that may have been relevant to the outcome of the experiment. Composition of lists, the order in which different lists were administered to *S*s, the order of the two conditions (ordered and random input sequences) in two experimental sessions, and perhaps even the order of specific items within a list are among variables that may have interacted with the experimentally manipulated variables of input and output positions. We believe, however, that the possible existence of these interactions does not invalidate the method used or the results obtained.

The practice of using two sets of lists containing identical responses deserves special comment. The reader will remember that for a given A-B list in Session 1 there was a corresponding A-Br list (same responses differently paired with the same stimuli) in Session 2. Despite the relatively long interval between the two sessions, learning of A-B lists may have interfered with learning and recall of A-Br lists. This possibility was examined by comparing the proportion of intralist intrusions in Session 2 which would have been correct in Session 1 (intrusions from A-B lists to A-Br lists) with the proportion of intralist intrusions in Session 1 which would have been correct in Session 2 ("pseudointrusions" across lists). It was found that the relative frequency of intrusions in Session 2 was significantly greater ($P < .02$) than the relative frequency of "pseudointrusions" in Session 1. Although such intersession interference effects do not constitute a serious problem for interpreting the data—unless one assumes that intrusions vary systematically with input and output positions of items in A-Br lists—their existence may have confounded some of the results.

Input and Output Interference

The results of the experiment clearly show that input and output position are very important determinants of intralist retention. Probability of recall of individual items was found to range from approximately .20 to 1.00, depending upon the position of the item in the input and output sequences. The systematic trends in the data provide information relevant to the hypothesis that intratrial forgetting is attributable to two different sources of intratrial interference, input and output.

In more traditional terminology, both these sources represent retroactive effects in retention. The present experiment, however, was based on the assumption that the effects of the two classes of interpolated events might be different. The existence of the well-known serial position curves did not deter us from adopting this position. Rather, we hoped that the separation of intratrial retroactive interference effects into the two sources might explain such curves. The typical U-shaped serial curve, under conditions where the output sequence is identical with the input sequence, for instance, might occur in a situation in which output interference is greater in extent than input interference and where there is interaction between the two sources of interference.

The findings suggest that while the notion of output interference is probably a useful one—probability of recall of late-input items decreases systematically with the number of intervening outputs—the concept of input interference requires certain qualifications. Recency effects, i.e., the observation that late input item are recalled more readily than middle input item, could be interpreted in terms of input interference, but primacy effects, i.e., higher recall of early input items than of middle ones, run counter to the notion of a simple input interference.

It is possible that *S*s rehearse material during the input phase (e.g., Anderson, 1960; Pollack, Johnson, and Knaff, 1959). Early input items would then be expected to benefit more from such additional reinforcement than later ones and would offer greater resistance to input interference. The fact that primacy effects are greater for ordered lists than for random lists provides some support for this hypothesis. In ordered input lists, stimulus items are completely redundant with the serial position of pairs, and association between the serial position and the response (Newman and Saltz, 1962) may be sufficient to permit discriminative responding in the output phase. Intratrial rehearsal of the order of response items may be more feasible than rehearsal of specific S-R connections, thus producing more prominent primacy effects in ordered input lists.

Although McGeoch and Irion (1952, p. 125) have pointed out the difficulties inherent in the rehearsal hypothesis, we are inclined to retain it until more appropriate explanations of primacy effects become available. For the time being, then, we assume that intratrial rehearsal and input interference combine to yield the serial position curve associated with the input sequence of items in a list, and that output interference is largely responsible for serial position effects associated with output.

Serial Position Curves

The present experiment suggests that the problem of intratrial retention of individual items presented for learning in context of other items, i.e., lists, is intimately related to the problem of serial position curve. The present data, however, cannot be readily related to previous experiments since those have usually involved serial lists rather than paired associates (McGeoch and Irion, 1952). In fact, some experiments using paired associates have failed to yield systematic serial position effects (Brown and Battig, 1962).

The present results show that the shape of the traditional serial position curve depends on the output position of items. Primacy effects are greater than recency effects when recall is tested late in the output sequence and smaller when recall is tested early in the output sequence. None of the theories discussed by McGeoch and Irion (1952, p. 125 ff.) include provisions for this fact. It is reasonable to argue that a similar interaction between input and output position might occur in recall of lists learned under the method of serial anticipation. Theories of serial position should eventually come to grips with it. More likely, however, is the possibility that serial position effects will be subsumed under the comprehensive theory of intratrial interference.

The present results are relevant to experiments which have demonstrated that the serial position curve in immediate free recall is roughly a mirror image of that obtained under conditions of serial anticipation (e.g., Deese and Kaufman, 1957). It has been argued (Deese, 1957) that this difference between the shapes of serial position curves is related to the "Marbe effect" (Bousfield, Cohen, and Silva, 1956; Bousfield, Whitmarsh, and Esterson, 1958) according to which the order of emission of items in free recall is determined by their order of "primitive strength" (the "spew principle" of Underwood and Schulz, 1960). In terms of the findings of the present experiment, the difference between serial position curves in serial and free recall can be attributed to the interaction between input and output positions in determining the probabiliy of recall of individual items: output interference affects late input items, but not early ones. The present findings also suggest that the "primitive strength" of an item is not a fixed quantity, but varies considerably over time in the output phase.

One-Trial versus Incremental Learning of Associations

The present experiment and its findings have certain implications for the current debate on the problem of all-or-none versus incremental establishment of associations (Estes, 1960; Rock, 1957; Underwood and Keppel, 1962). Since *S*s are capable of recalling an item with probabilities approaching unity immediately after the presentation of the item, one must conclude either that the association is established on a single trial or that the probability measure does not reflect the strength of the association faithfully in the situation. This is not the place to argue the merits of these two positions. What seems to be clear, however, is the fact that probability of recall of an item, following an intratrial interval, however short, reflects not only the strength of the original association, but also the effects of input and output interference. In this sense, then, "miniature experiments" of the type suggested by Estes (1960) are experiments in short-term retention, and might profitably be analyzed from this point of view. Estes' "pattern model with imperfect retention" (Estes, 1961) seems to be a step in this direction. It is not at all unlikely that the parameters of that model can be shown to be functions of various sources of intralist interference.

SUMMARY

This experiment was concerned with intralist retention of paired associates. On the basis of the observation that an item is practically always recalled immediately after its presentation and that its recall is less than perfect when other items are presented for learning (input) and attempted recall (output) in the intralist retention interval, two sources of intratrial interference, associated with the operations of inputting and outputting, were postulated as being responsible for the decreasing availability of the learned item in recall.

An experimental design was used that permitted the separation, and the evaluation of the effects, of these two sources of interference. This was done by systematically varying the sequence in which list items were recalled. Each of 50 *S*s learned 20 lists of ten paired associates under different conditions of input and output sequence on a single trial. The results can be summarized as follows. (1) In general, probability of recall of an individual item is greatly affected by the position of the item in the input and output sequence. (2) When the item in the last input position is recalled in the first output position, its retention is practically perfect. (3) The probabilities of recall of items under other combinations of input and output position vary considerably, in some cases being as low as .20. (4) The recall of items in early input positions is relatively little affected by their position in the output sequence. (5) The recall of items in late input positions decreases systematically with their position in the output sequence.

These findings were evaluated in the light of the two hypothesized sources of intratrial interference. Apart from the finding of primacy effects—higher recall of early input items than of middle input items—the data seemed to reflect the operation of input and output interference. The previously reported findings that the shape of the serial position curve differs under conditions of serial and free recall were discussed in terms of the observed interaction between input and output position of individual items. Some implications of the findings for the problem of one-trial versus incremental learning of associations were also briefly mentioned.

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