

## INPUT AND OUTPUT INTERFERENCE IN SHORT-TERM ASSOCIATIVE MEMORY<sup>1</sup>

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A single paired-associate unit (critical unit) was presented in a fixed position in a series of other similar units and its recall tested either once or twice, following various combinations of interpolated inputs and outputs in the short retention intervals. Probability of recall of the critical unit on the 1st test was higher following 2 interpolated outputs than 2 interpolated inputs, while probability of recall on the 2nd test seemed to depend on the nature of interpolated events in a more complex fashion. The findings were interpreted in terms of differences in the ease of coding the critical unit with respect to its position in the input and output sequences.

When a single paired-associate (PA) unit is presented in a series of similar units and tested for recall a very short time after its presentation, its probability of recall has been shown to depend on the number of other units presented for study and recall in the retention interval (e.g., Arbuckle, 1964; Murdock, 1961, 1963a, 1963c; Peterson, Saltzman, Hillner, & Land, 1962; Tulving & Arbuckle, 1963). In some of these experiments it is possible to compare the effects of interpolation of study units (input units) on the recall of a given unit with that of interpolation of recall units (output units). These comparisons show that recall is higher following interpolated outputs than following the same number of interpolated inputs.

Tulving and Arbuckle (1963) presented to Ss series of 10 PA units consisting of single digits as stimulus items and common words as response items.

<sup>1</sup> This research was supported by the National Science Foundation under Grant No. GB-810. The paper was prepared for publication while the senior author was a National Research Council of Canada Senior Research Fellow at the Institute of Human Learning, University of California at Berkeley.

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Under the condition that mimicked serial learning (referred to as ordered input condition in the experiment), recall of a single PA unit was higher after  $n$  interpolated outputs than after  $n$  interpolated inputs, provided that the recall data from the first few items in the input sequence, showing a pronounced primacy effect, were omitted from consideration. Thus, following 1, 2, 3, 4, 5, and 6 interpolated outputs, probability of recall was .84, .66, .52, .50, .46, and .44, respectively, whereas following the same number of interpolated inputs the probability of recall was .76, .50, .48, .44, .24, and .22, respectively. Similar data have been obtained by Arbuckle (1964), who used digit-word pairs in lists of 6, 9, and 12 units, and by Murdock (1963a, Exp. III), who used lists of 6 PA units consisting of words. In all these studies the length of the retention interval varied with  $n$ , but it was constant for corresponding numbers of interpolated inputs and outputs.

On the basis of these observations it might be concluded that when the length of retention interval is constant, input interference in short-term associative memory is greater than output

interference, but the evidence is not conclusive. In all the experiments cited, lists of a fixed length were used. This means that the effects of output interference are inferred from the recall scores of the last unit in the list, while the effects of input interference are inferred from the recall scores of other units in the list. Thus the nature of events in the intratrial retention interval, under these conditions, is confounded with the position of a unit in the list. If *S* pays unequal attention to different units in the list, or for some other reason does not "learn" all units to the same degree, no comparison between input and output interference is justifiable. For example, if the last unit in the list is fixated more strongly than others, then the findings mentioned above could at least partly be accounted for in terms of differential learning rather than in terms of differences in input and output interference.

The experiment reported in this paper was designed to compare the effects of input and output interference under conditions where differential learning effects were excluded. A single PA unit, the "critical unit," always occupying the same position in the input series of similar units, was tested for recall following various numbers of interpolated inputs and outputs. Some of the critical units were tested for recall twice, in accordance with the RTT paradigm (Estes, 1960). Thus, the experiment provided data on recall probabilities of the critical unit on both the first and the second recall test as a function of number and nature of events interpolated in the single retention interval or two successive intervals.

The experiment was in many ways similar to a series of experiments reported by Peterson et al. (1962), except that in the present experiment the events in the intratrial retention in-

tervals were classified as to their nature (inputs or outputs).

#### METHOD

*Design.*—The first recall test of the critical unit (Test 1) followed Interval A filled with events described in Table 1. The interpolated events were defined in terms of all combinations of zero, one, or two interpolated inputs with zero, one, or two interpolated outputs. To facilitate exposition, the nine conditions of interpolation in Interval A are numbered and will be referred to as shown in Table 1. Thus, for instance, Cond. 1 refers to the testing of the critical unit immediately after its presentation, following no other inputs or outputs; under Cond. 3, recall of the critical unit was tested following two outputs of "dummy" items; under Cond. 5, it was tested following one input and one output, or one output and one input; and so forth.

The second recall test (Test 2) was given only for those units that were tested on Test 1 under Cond. 1, 3, 7, and 9. The second retention interval of these units (Interval B) contained either two additional inputs (Cond. 1) or two additional outputs (Cond. 0).

All *Ss* served under all experimental conditions, with the order of conditions counterbalanced among *Ss*. Each *S* was given two tests for each of the nine conditions with respect to Test 1, and one test for each of the eight conditions with respect to Test 2.

*Materials.*—The PA units consisted of common adjectives as stimulus items and single digits from 1 to 9 as response items. These items were printed in black India ink on white 3 × 5 index cards, with both the stimulus and response item on input cards and the stimulus item alone on output cards.

TABLE 1  
DESIGN OF THE EXPERIMENT WITH RESPECT TO INTERVAL A BETWEEN THE PRESENTATION AND TEST 1 OF THE CRITICAL UNIT

Number of Interpolated Inputs	Number of Interpolated Outputs		
	0	1	2
0	1	2	3
1	4	5	6
2	7	8	9

The cards were arranged into series of 9-16 units.

Eighteen different series were used, two for each of the nine conditions in Interval A. Each series began with five inputs. The first four inputs served as dummies to eliminate possible primacy effects and provided materials for interpolated outputs where required. The fifth input unit in each series was the critical unit. Eight of the 18 series, corresponding to Cond. 1, 3, 7, and 9 of Interval A, included a second recall test of the critical unit. In one of the two series corresponding to each of these four Interval A conditions, the critical unit was tested following two further inputs, in the other it was tested following two outputs of dummy units.

Examples of some of the series used in the experiment are shown in Table 2. Series 1-I yielded recall data for the critical unit (TIRED 8) on Test 1 immediately after its presentation (Cond. 1 of Interval A), and on Test 2 following two interpolated inputs in Interval B (Cond. I). Series 5 included only Test 1 of the critical unit (GENTLE 4) following one output and one input in Interval A. Series 7-O tested the critical unit (HEARTY 7) following two interpolated inputs in Interval A and two interpolated outputs in Interval B. Different kinds of series, as well as additional tests of dummy units in each series after the final test of the critical unit, as shown in Table 2, served to camouflage the critical unit in the series. In Table 2, the stimulus items of critical units are shown in capital letters, but in actual series, of course, they were not distinguished from the other units in any way.

*Subjects.*—The Ss were 144 adults of both sexes enrolled as students in various psychology courses at the University of Toronto in the summer of 1963. Their median age was 27 yr. None of the Ss had previously participated in an experiment of this type, although some had served in other psychological experiments.

The first set of 72 Ss were tested with the 18 series as described above. For the second set of 72 Ss the critical units in the 18 series were counterbalanced among Ss. The response item remained always the same in a given series, but the stimulus item varied. This arrangement eliminated the confounding between experimental conditions and specific critical pairs present in the first set. Since the overall pattern of results was very similar for both sets, no further distinction will be made between the two sets

TABLE 2  
EXAMPLES OF SERIES USED IN  
THE EXPERIMENT

Set 1-I	Set 5	Set 7-O
unknown 9	upright 8	polite 3
divine 1	hostile 6	healthy 4
silly 5	deadly 2	ready 1
severe 4	active 1	formal 6
TIRED 8	GENTLE 4	HEARTY 7
TIRED	hostile	fiery 5
wooden 3	unseen 9	sturdy 9
remote 6	GENTLE	HEARTY
TIRED	upright	formal
remote	unseen	sturdy
		HEARTY
		polite

of Ss. All the data reported below apply equally well to both arrangements.

*Procedure.*—All Ss were tested individually. At the beginning of the session S received rather detailed instructions to familiarize him with the task. He was told about the nature of the materials, about the total number of series he would be exposed to, the fact that series would differ from one another, and the fact that once he had finished with a series he would not be asked to recall any part of it again at a later time. More specifically, S was told to read out aloud both the adjective and the digit when the two appeared together on a card, and to say the correct digit whenever an adjective alone was presented. When he was not sure of the correct answer he was to respond with the first digit that came to mind. Thus guessing was not only encouraged but insisted upon. That these instructions were effective was shown by the fact that there were fewer than 2% response omissions. The S was also told that sometimes an adjective would be shown alone more than once in a given series and that his task was to say the right digit every time this occurred. The S was not informed, of course, that one of the pairs was of especial interest to E.

Prior to the first experimental series, S was given preliminary practice on three practice series in which both the stimulus and response items were monosyllabic words, but which otherwise resembled the experimental series in their composition. These practice lists were administered to acquaint S with the nature of the task, and to reduce initial warm-up effects.

The cards with stimulus materials were presented by means of a manually operated

TABLE 3  
PROPORTION OF PA UNITS RECALLED ON  
TEST 1 AS A FUNCTION OF NUMBER OF  
INTERPOLATED INPUTS AND  
OUTPUTS

Number of Interpolated Inputs	Number of Interpolated Outputs		
	0	1	2
0	1.00	.83	.48
1	.80	.49	.29
2	.36	.32	.31

card holder attached to a plywood screen that separated *E* from *S*. All cards belonging to a given series were stacked in the holder in the 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. Its removal constituted the beginning of the series. Cards were exposed at a constant rate of 2 sec/card, with no intervals between exposures. Thus the length of Interval A varied from 0 to 8 sec., while the length of Interval B, whenever it occurred, was always constant at 4 sec.

All responses given by *S* were recorded by *E*. No knowledge of results was provided to *S* until the end of the whole session.

### RESULTS

*Test 1.*—Proportions of critical units recalled on Test 1 for various combinations of inputs and outputs interpolated in Interval A are shown in Table 3. Each entry in Table 3 is based on a total of 288 responses, two responses from each of 144 *S*s. Of primary interest in Table 3 is the comparison between the first row, showing probability of recall following zero, one, and two interpolated outputs, and the first column, showing probability of recall following zero, one, and two interpolated inputs. Immediately after the presentation, the recall of the critical unit was practically always successful. Only one error occurred in 288 tests under Cond. 1. Probability of recall was approximately equal following one interpolated input and one interpolated output, with

a small but clearly insignificant advantage for the recall following the output. Recall following two interpolated outputs, however, was higher than it was following two interpolated inputs. The difference between the two proportions (.48 and .36) was significant at the .01 level, on the basis of the test for correlated proportions (Ferguson, 1959, p. 148).

Table 3 also shows that when an interpolated output was added to two interpolated inputs in Interval A (Cond. 8), the probability of recall decreased only slightly, from .36 to .32, whereas the addition of an interpolated input to two interpolated outputs (Cond. 6) produced a larger decrement, from .48 to .29. The addition of yet another interpolated unit (Cond. 9) did not seem to have any further effect on probability of recall. It looks as if the recall probability might have reached the asymptote after three interpolated items. The level of recall in Cond. 6, 8, and 9 agrees well with the asymptotic value of the short-term memory function from various other studies (Murdock, 1963b).

TABLE 4

PROPORTION OF PA UNITS RECALLED ON TEST 2, GIVEN THAT THE UNIT WAS RECALLED ON TEST 1, FOR BOTH CORRECT ( $C_1C_2$ ) AND INCORRECT ( $I_1I_2$ ) TEST 1 RESPONSES, AS A FUNCTION OF NUMBER OF INTERPOLATED INPUTS AND OUTPUTS IN THE FIRST AND SECOND RETENTION INTERVALS

Events in the First Interval (A)	Events in the Second Interval (B)			
	2 Inputs		2 Outputs	
	$C_1C_2$	$I_1I_2$	$C_1C_2$	$I_1I_2$
0 Inputs, 0 Outputs	.51	—	.68	—
0 Inputs, 2 Outputs	.71	.48	.50	.36
2 Inputs, 0 Outputs	.61	.48	.68	.47
2 Inputs, 2 Outputs	.56	.36	.56	.32

*Test 2.*—A summary of Test 2 data is presented in Table 4. The entries in Table 4 are conditional probabilities of two kinds of events, (a) probability that a correct response on Test 1 was again recalled correctly on Test 2 ( $C_1C_2$ ), and (b) probability that a given incorrect response on Test 1 was repeated on Test 2 ( $I_1I_2$ ).

As mentioned earlier, when the critical unit was tested for recall on Test 1 in absence of any interpolated activity, it was practically always recalled correctly. Table 4 shows that the probability of correct recall of these units on Test 2 was higher following two interpolated outputs in Interval B (.68) than following two interpolated inputs (.51). The difference between these two proportions was significant at the .01 level.

Critical units tested on the first recall test following two interpolated outputs in Interval A yielded a higher probability of recall on Test 2 when Interval B was filled with two inputs (.71) than when it was filled with two outputs (.50). The same was true of incorrect responses given on Test 1. On Test 2 the same incorrect response was given again by Ss more frequently following two interpolated inputs (.48) than two outputs (.36). Unfortunately, no appropriate statistical tests seem to be available for testing the significance of these differences. In view of the absolute size of these differences and in view of the fact that the data were very similar on both sets of 72 Ss, they can probably be regarded as quite reliable.

The nature of units interpolated in Interval B did not seem to have any large or obvious systematic effect on probability of recall on Test 2 when the critical unit was first tested under Cond. 7 (2 inputs, 0 outputs) or Cond. 9 (2 inputs, 2 outputs) of Interval A.

## DISCUSSION

The major finding of the present experiment was that probability of recall of a single PA unit a few seconds after its presentation is higher following two interpolated outputs than following two interpolated inputs. Both Test 1 data under Cond. 3 and 7 and Test 2 data under Cond. 1-I and 1-O supported this conclusion. In the latter case the overall level of recall was higher than in the former case, corroborating similar findings reported by Peterson et al. (1962, Exp. IV), but the differences in recall as a function of interpolated inputs and outputs were equally clear in both cases.

Since the critical units occupied the same input position in all series, they must have been "learned" to the same extent under all experimental conditions. It would seem reasonable, therefore, to attribute the differences in their recall after a fixed interval to differences in interference effects produced by interpolated inputs and outputs. Input interference in short-term associative memory is greater than output interference.

This finding makes sense if we assume that short-term memory storage has a limited capacity. The addition of interpolated units to other units already in the storage under the conditions where interpolated events are inputs might result in the displacement of some of the stored units, including the critical unit, with the consequence that the probability of recall of the critical unit decreases. But if we accept this interpretation, additional mechanisms have to be postulated to account for the decrement in recall following interpolated outputs and for the findings on Test 2 under Cond. 3-I and 3-O. Under the latter conditions, recall of the response item given by S on Test 1, whether correct or incorrect, was greater following two interpolated inputs in Interval B than following two interpolated outputs. These findings cannot be easily reconciled with the hypothesis that interpolated inputs displace previously stored units.

A somewhat more promising hypothesis is that the critical unit can be recalled more readily if its initial presentation or first recall occurs in a position in the overall series of inputs and outputs that can be more efficiently coded by *S*. The critical units under Cond. 3 were in the final position of a "run" of other inputs, while those under Cond. 7 were more in the middle of the run. If *S* codes or "tags" (Yntema & Trask, 1963) both items of input units with respect to their position in the sequence, and retrieves some of the response items in terms of their position tags rather than in terms of a direct association between the stimulus and response item, recall would be higher for units that have been tagged more efficiently. The first recall test of the critical item under Cond. 3-I occurred in the final position of a run of three outputs, while under Cond. 3-O it occurred in the middle of a run of five outputs. Serial-position tagging of the stimulus item of the critical unit and the response item given by *S* to it in the first recall test, whether correct or incorrect by *E*'s criteria, might have been facilitated by the distinctiveness of the position of the unit in the overall series, resulting in higher conditional recall probability of the critical unit under Cond. 3-I than Cond. 3-O.

The serial-position coding hypothesis is admittedly tenuous. As more empirical information becomes available about factors affecting short-term memory of single units of material, better interpretations of the findings reported in this

study might suggest themselves. For the time being, however, the explanation of input and output interference effects in terms of coding operations performed by *S* on units to be retained would seem to be reasonable.

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(Received April 23, 1965)