Journal of Experimental Psychology
1972, Vol. 96, No. 2, 400–406

INTERFERENCE IN SHORT-TERM RETENTION OF DISCRETE MOVEMENTS [1]

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The retention of discrete lever movements was examined, with additional movements of the same lever interpolated in a 12-sec. retention interval. In Exp. I, the position within the retention interval of one or two interpolated movements was varied. The absolute error of recall was significantly greater as the amount of interpolated material increased, and as its position moved toward the end of the retention interval. In Exp. II, four types of movements, ranging from a complete active movement to a complete passive movement, were interpolated. Forgetting was directly related to the amount of motor output during the retention interval, indicating that the most important information used to encode a discrete movement is the motor output required to execute it.

Williams, Beaver, Spence, and Rundell (1969) have shown that retroactive interference effects can be demonstrated in the short-term retention of discrete motor movements. Such movements, however, may be seen as involving a number of distinct components, such as the motor output required for the movement or the feedback the movement generates. The present experiments were designed to determine how much of the total interference effect is attributable to each of these components. It can then be argued that the original movement is encoded in terms of those components which produce the greatest interference effects.

Experiment I

The original design for an experiment to compare various interference effects involved interpolating different movement components at different positions within the retention interval. It was first necessary, therefore, to determine whether position of interpolation itself had any differential effect on retention in this situation.

Method

Apparatus.—The apparatus used was the same in both experiments. Fitted to a right-handed student's desk chair was a lever which could rotate in a horizontal plane through an angle of 130°. In its left-most position, the lever was parallel to *S*'s frontal plane. It was equipped with an elbow support and an adjustable vertical bar, which *S* gripped with his hand. In Exp. I, the lever was always moved by *S*. In Exp. II, it was sometimes moved by means of a bidirectional motor and a clutch. In either case a brake stopped the lever's movement when necessary. With the clutch engaged and the motor on, the arm rotated at 54 rpm, and under these circumstances a torque of 15 kg.-cm. was sufficient to cause the clutch to slip and the arm to stop moving. There was a shield over the lever so that *S* was not able to see either the lever or his arm.

Instructions were presented to *S* on a cathode-ray display controlled by a PDP-1 computer. The computer was also used to control the motor power and direction, the clutch and the brake, and to monitor the position of the lever.

Design.—Each *S* was presented with 96 trials, comprising eight experimental conditions, six target angles, and two replications, in a factorial design. The trials were presented in random order, with the exception that one replication was completed before the other was begun. Any difference between the replications therefore constitutes a practice effect. The target angles which were used ranged from 15° to 40° in 5° steps.

A preliminary experiment revealed that the size of the target angle and the direction of its presenta-

[1] This report is based on a dissertation submitted by the author to the Horace H. Rackham School of Graduate Studies, University of Michigan, in partial fulfillment of the requirements for the PhD degree. The research was supported by the Advanced Research Projects Agency, Department of Defense, and monitored by the Air Force Office of Scientific Research, under Contract AF 49(638)-1736 with the Human Performance Center, Department of Psychology, University of Michigan. Reproduction in whole or in part is permitted for any purpose of the United States Government. The author is indebted to A. W. Melton for his advice and encouragement, and for his critical reading of a draft of this paper.

[2] Requests for reprints should be sent to A. S. Faust-Adams, who is now at the School of Psychology, University of New South Wales, Kensington, New South Wales 2033, Australia.

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tion had significant effects on algebraic error, but none of the interactions involving these factors were of interest. In the present experiment, the Angles × Direction of Presentation and Angles × Direction of Recall interactions were therefore confounded with the *S*s effect. Within each *S*, each angle was paired, in a balanced incomplete-block design, with only one of the four possible combinations of the two directions of presentation and the two directions of recall. Across every four *S*s, however, all possible combinations occurred equally often.

The retention interval in this experiment was 12 sec., permitting four interpolated movements, one in each of four 3-sec. intervals into which the retention interval was conceptually divided. In each of the eight different treatment conditions, the retention interval was filled differently. In Cond. 1, the retention interval was unfilled. In Cond. 2, 3, and 4, it was filled with just one interpolated movement. In Cond. 2, this movement occurred in the first position, i.e., in the first of the four 3-sec. intervals. In Cond. 3 it occurred equally often in each of the two middle positions, and in Cond. 4 it occurred in the last position. In Cond. 5, 6, and 7, two movements occurred in the first two, the middle two, and the last two positions, respectively. Finally, in Cond. 8, the retention interval was completely filled with four interpolated movements. The various ways in which the retention interval was filled are shown schematically in Table 1.

The construction of each trial.—For each trial, the starting point for the target movement was chosen from within a 90° "working range," placed in the center of the lever's 130° movement range. There was, therefore, an additional 20° of movement at either end before the lever struck against the fixed stops. The starting point for all movements was chosen randomly, but with the restriction that if each movement was made accurately the lever would never move outside the working range.

In Cond. 2 through 8, interfering movements were interpolated between presentation and recall, each movement taking approximately 3 sec. The finishing point for each of these movements was chosen randomly from the working range, with the restriction that each movement should be at least 5° in extent. The starting position for recall was always chosen with the restriction that *S* could not predict the direction of recall.

Procedure.—Each trial, including the first, began with the display of the word REST for 8 sec. During this period the lever was set to the starting position for that trial. At the end of this period, the words GRASP LEVER were displayed for 4 sec., and *S* was instructed to rest his arm on the lever at that point. The words MOVE AND REMEMBER then appeared, with an arrow beneath them indicating to *S* the appropriate direction for him to move. On this signal, *S* moved the lever in the direction of the arrow until the brake came on.

For Cond. 1, and for the rest portions of the retention interval in Cond. 2 through 7, the screen remained blank, and *S* was instructed to keep his arms still until some instruction appeared. When an interpolated movement was to be presented, a number and an arrow appeared on the screen at the beginning of the 3-sec. interval. The number represented the distance in degrees through which *S* was to try and move the lever, while the arrow indicated the direction. After this display had been on for 1 sec., the word MOVE appeared above it. The *S* was instructed not to move until this appeared. Once *S* started moving, the lever's position was read every 200 msec., and the end of the movement was defined as having occurred if the lever's position did not change by more than 2° in any 200-msec. period. The *S* was allowed 2 sec. to complete the movement, making 3 sec. in all for each interpolated event. Instructions stressed that each movement had to be made smoothly and deliberately and that corrections could not be made once *S* stopped moving.

TABLE 1

Location of the Interpolated Movements within the Retention Interval for Each of the Treatment Conditions, with the Associated Algebraic Error and Its Variance, Experiment I

Condition	3-sec. interval[a]				Algebraic error	Variance
	1st	2nd	3rd	4th		
1					− .92	58.98
2	X				−1.24	61.64
3		X - - -	- X[b]		− .73	61.12
4				X	.95	75.60
5	X	X			− .16	57.16
6		X	X		− .39	65.01
7			X	X	.12	84.68
8	X	X	X	X	− .16	80.04

Note.—Algebraic error is measured in degrees.
[a] An X indicates the presence of interpolated material.
[b] Material is divided between these two positions.

At the end of the retention interval the word RECALL was displayed, together with an arrow indicating the direction. This was a signal for *S* to try to move the lever through the target angle, 3 sec. being allowed for him to complete the movement. Finally, the word REST appeared, which was a signal for *S* to take his arm off the lever and rest it in his lap.

Whenever *S* made a mistake by failing to follow directions, a signal such as WRONG DIRECTION appeared for 2 sec. to indicate the nature of the mistake. This was followed by REST, then by the beginning of the next trial. The aborted trial was then automatically repeated at the end of an arbitrary block of trials in which it occurred.

Each *S* was given two short practice periods. The first period continued until *S* had completed five consecutive trials without any mistakes, such as moving in the wrong direction. Instructions were then given on the bonus system, which was 3¢ each time *S* reproduced the angle to within ±2° of its correct value. During the second practice period, *S* was told after each trial whether or not he had attained the criterion, and the practice ended when he

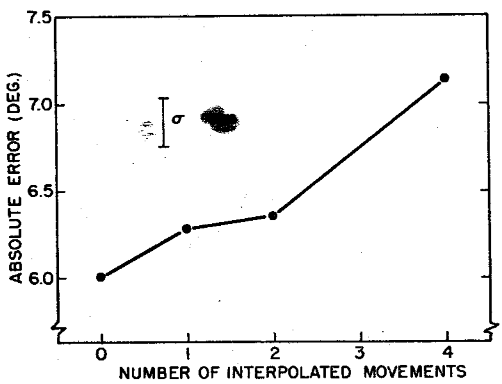

FIG. 1. Absolute error as a function of amount of interpolated material.

had attained it three times, or had completed 10 trials, whichever took longer.

Subjects.—The *S*s were 28 right-handed males who had volunteered to serve in paid experiments. They were paid at the rate of $1.50 per hour, plus a bonus based on performance. All were naive to motor-retention experiments.

Results and Discussion

The dependent variables were the absolute and algebraic errors to the nearest degree. The experiment involved a total of 2,688 trials, of which 75, or 2.8%, were missing. Although trials on which *S* made an error were repeated, there were some occasions when the paper tape was misread, with the result that an impossible trial was attempted. In such cases, the program automatically continued with the next trial. Since there was no case in which a trial was missing from both first and second replications, each missing trial was simply replaced with the corresponding value from the other replication, and the degrees of freedom were reduced where appropriate.

A four-way analysis of variance was carried out on the absolute errors, the factors being *S*s, practice, treatment conditions, and angles. The treatment conditions will be discussed below. Although the practice effect was not significant, the angle effect was significant, F (5, 135) = 7.30, $p < .001$. There were significant interactions of *S*s with treatments, F (189, 870) = 1.39, and of *S*s with angles, F (135, 870) = 3.67, both ps < .01. These reflect greater variability across treatments and angles for some *S*s than others.

The overall effect of amount of interpolated activity is shown in Fig. 1. The data have been averaged across Cond. 2, 3, and 4 to give the mean effect for one interpolated movement, and across Cond. 5, 6, and 7 for two movements. The significance of the effect of number of interpolated movements was tested with a planned comparison in which weights of −3, −1, −1, −1, 1, 1, 1, and 3 were used for the eight treatment means in order. The results were significant at the 5% level, F (1, 189) = 6.54, showing a direct increase in absolute error with an increase in the number of interpolated movements, the retention interval remaining fixed.

The effect of varying the position of interpolation within the retention interval is shown in Fig. 2. In order to test this effect, separate analyses of variance were carried out for one and for two interpolated movements. There was a significant effect of the position of the two interpolated movements, F (2, 54) = 5.51, $p < .01$, but not for one movement, F (2, 54) = 1.32. No interactions reached significance in either of these analyses.

Since Bilodeau (1966) has suggested that the variance of errors will increase as a result of forgetting, the variances associated with the treatment conditions were examined and are given in Table 1. It is not appropriate to carry out a series of pairwise F tests on these results, but Cochran's C test for homogeneity of variance (Winer, 1962, p. 94) was carried out. For the three variances involving one interpolated item (Cond. 2, 3, and 4), C = .38, and for two items (Cond. 5, 6 and 7), C = .41. Both of these are significant at $p < .05$, indicating significantly nonhomogeneous variances. An examination of the individual variances indicates that, with the exception of Cond. 2 and 3, which are almost identical, there is an increase in the variance of the recall as the interpolated material moves toward the end of the retention interval.

No immediate explanation of this is apparent, but one possibility is that the closer the interpolated material is to the recall, the greater the likelihood of response competition between the interpolated and retained movements. If this is so, there should be some relationship between the similarity of the interpolated and retained movements and recall performance. Alternatively, there might be some relation between the angles recalled and the interfering items, which would be analogous to finding intrusions in the verbal situation.

These two possibilities were examined for trials in Cond. 7, where two interpolated movements appeared at the end of the retention interval. The first possibility was examined by calculating the regression of the absolute difference between the angle presented and each of the two interpolated angles. In all cases the angle actually executed was used. The multiple-regression coefficient was .09, which is not significant. The second possibility was examined by calculating the regression of the angle recalled on the two interpolated angles. The result was not significant, the coefficient being .08. Finally, the regression of absolute error on the sizes of the two interpolated angles was calculated, with the aim of examining the hypothesis that larger interpolated angles might produce larger errors, without regard to the sign of the error. The regression, with a coefficient of .07, was again not significant.

Experiment II

The results of Exp. I suggest that the size of the interpolated angles does not affect retention in this situation. Another possibility is that the nature of the interpolated movement itself has some effect. It is known that an active movement of the same general type as that being retained will cause an increase in forgetting, while at the other extreme, neither the writing nor the mental activity involved in an interpolated paper-and-pencil task has any effect (Williams et al., 1969). The present experiment examined this dimension by interpolating movements which involved various components of the retained movement.

Four components were chosen as being both tractable and theoretically interesting.

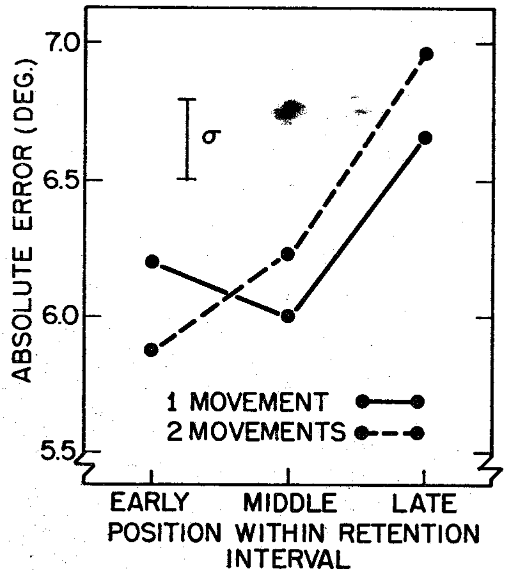

Fig. 2. Absolute error for one and two interpolated movements as a function of the position of the movements within the retention interval.

The first is the preparation or planning of a movement. Welford (1968, p. 140) suggests that brief movements such as the present discrete motor movement are "ballistic," in that they are initiated and carried out as a single unit, with *S* monitoring feedback only from the beginning and end of the movement.

This preparation component was manipulated by interpolating some items in which *S* was given the angle and direction to move through, but then told DON'T MOVE instead of MOVE. This will be referred to as a Movement Preparation item. In the previous experiment, the angle and direction were displayed for 1 sec. prior to the MOVE signal. The same applied in this case, and it was again stressed that *S* should move as quickly as possible if MOVE appeared. It is therefore assumed that when DON'T MOVE appeared, *S* used the prior 1-sec. period to prepare the movement, even though it was not actually executed.

The second component was the actual initiation of the movement, including whatever feedback might result from such initiation. The item which involved this component, the Movement Initiation item, also involved the first component mentioned above. In other words, S was asked to prepare and initiate the movement, but once he moved 2° from the starting point the apparatus took over and finished moving his arm through the displayed angle.

In performing both of these interpolated items, S was to be exposed for at least 1 sec. to a display which indicated in degrees the extent of the movement. If both of these two items are just as detrimental to recall as the complete movement used in the previous experiment, the display of this number may be responsible. The S may transform the number into his own measure of the extent of the movement, and this in itself may be sufficient to affect the retention of the original item. The possibility that such an effect may be important was checked by including an item identical to the second, except for the absence of the number indicating the movement extent. This will be referred to as a Movement Initiation without Display item. For this item, S was required to initiate the movement, but he had no idea how far the machine would move his arm once it took over.

The final component which was examined involved all those aspects of the movement that are not involved in the initiation and execution by S. This component will be termed the feedback component, but it would be best to define it operationally, in terms of the Passive Movement item which was used to measure it. The S saw the angle and direction display, but at the end of the 1-sec. period the word RELAX appeared on the screen, and the apparatus moved S's arm through the displayed angle. The S was therefore subjected to much of the feedback involved in making the complete movement.

Method

Design.—Details of the design which are not mentioned were the same as in Exp. I. Each S received 84 trials made up of 7 Conditions × 6 Angles × 2 Replications. The 7 conditions differed only in the ways in which the retention intervals were filled. They are as follows: In Cond. 1 there were four Movement Preparation items; in Cond. 2, four Movement Initiation items; in Cond. 3, four Movement Initiation without Display items; and in Cond. 4, four Passive Movement items. In Cond. 5 there were four Active Movement items, exactly as in Cond. 8 of Exp. I. Cond. 6 was a rest condition in which the retention interval was unfilled, exactly as in Cond. 1 of Exp. I. Finally, Cond. 7 was a control condition in which Active Movement and Movement Preparation items were mixed in equal numbers. Without Cond. 7, S would have known that one Movement Preparation item always indicated that three more were to come, and he would not have prepared the subsequent movements.

Procedure.—Changes in the procedure from Exp. I were relevant to the new items used. If S resisted during any of the conditions involving passive movement, so that the clutch slipped and the lever did not reach the finishing point by the time the 3 sec. were up, the error signal YOU MUST RELAX was displayed. A Movement Initiation item was signaled by the appearance of a diamond around the number indicating the size of the angle, while for a Movement Initiation without Display item, the diamond appeared, but there was no number inside it

Three practice periods were given, introducing S gradually to the various conditions.

Subjects.—There were 32 right-handed male Ss drawn from the same source as for Exp. I. All were again naive to motor-retention experiments, and they were given the same base pay and bonus as before.

Results and Discussion

Of the 2,688 trials, a total of 101, or 3.6%, were missing because of apparatus failure. These were estimated, as in Exp. I, by replacing each with the corresponding value from the other replication, and the degrees of freedom were reduced where appropriate.

In an analysis of variance on the absolute errors, two of the main effects were significant: angles, F (5, 155) = 10.74, $p <$ .001, and treatment conditions, F (6, 186) = 2.34, $p < .05$. The treatment conditions effect was subjected to an F test, since no contrasts were planned on the means. There were two significant interactions: Ss × Angles, F (155, 829) = 2.06, $p < .001$, and Treatment × Angles, F (30, 829) = 2.78, $p < .001$, for which the explanations are as previously given.

An examination of the algebraic errors in both the experiments indicated that the same main effects were significant in all the absolute-error and algebraic-error analyses. There were many significant interactions in the algebraic-error analyses, making interpretation of the main effects difficult. The angle effects, however, were highly consistent in both experiments (in each case $p < .001$), and are shown in Table 2. In each case there is undershooting for the three largest angles and overshooting for the three smallest.

Table 3 shows the treatment condition means for the absolute error. Since the treatment condition means were not on any type of scale, and there were no specific prior hypotheses about their order, posterior comparisons were carried out using Duncan's new multiple-range test (Duncan, 1955), the results of which can be summarized schematically as follows: 4162375. Treatment means not underlined by a common line differ significantly, the significance level being 5% or better.

It is clear that Cond. 5 (Active Movement) produced recall which is significantly worse than almost all the other conditions. The difference between the means for Cond. 3 (Movement Initiation without Display) and Cond. 5 was .737°, while the difference required for significance at the 5% level was .745°. This suggests that Cond. 2 and 3 (the two Movement Initiation conditions), while not significantly different from each other, have together a significantly smaller effect than Cond. 5 (Active Movement). Removing from the display of Cond. 2 (Movement Initiation) the number which tells S how far he will be moving clearly has no effect on the results. Similarly, simply asking S to prepare a movement without actually making one has no significantly detrimental effect on recall. In fact, both Cond. 1 (Movement Preparation) and Cond. 4 (Passive Movement) produced mean errors slightly below that of Cond. 6 (Rest).

The interpolation of passive movements, as shown by the results of Cond. 4, obviously has no detrimental effect on recall. The kinesthesis generated by these passive movements would be very similar to the kinesthetic feedback produced when S makes an active movement. The fact that no significant interference was produced by the passive movement therefore suggests that under normal circumstances S does not remember the angle he moves through in terms of any transformation of the feedback it generates. This is in keeping with physiological evidence indicating that a response can be learned without kinesthetic feedback, and that a consistent response can be executed without such feedback (Lashley, 1917; Laszlo, 1967; Taub, Bacon, & Berman, 1965).

TABLE 2

Mean Algebraic Errors for the Target Angles, Experiments I and II

Exp.	Angle 15°	20°	25°	30°	35°	40°
I	2.35	2.43	.39	−.81	−2.47	−3.78
II	2.50	2.31	.29	−2.32	−3.31	−3.95

Note.—Algebraic errors are measured in degrees.

TABLE 3

Mean Absolute and Algebraic Errors and Algebraic Error Variances for the Treatment Conditions, Experiment II

Treatment condition	Absolute error	Algebraic error	Variance
1. Movement preparation	5.68	−.58	52.90
2. Movement initiation	5.86	−1.01	55.87
3. Movement initiation without display	5.91	−.49	57.79
4. Passive movement	5.60	.57	51.98
5. Active movement	6.65	−.15	77.27
6. Rest	5.76	−2.60	47.35
7. Control	6.17	−.97	61.44

Note.—Algebraic errors are measured in degrees.

The variances for the algebraic errors shown in Table 3 were examined with Cochran's test, giving $C = .19$, $p < .01$. The variances are in the same order as the mean absolute errors, except for Cond. 6 (Rest), which has the smallest variance.

It seems that the important variable affecting retention is the amount of active movement made by S during the retention interval, since only interpolated items involving complete active movements have a significantly detrimental effect on recall. Further support for this conclusion is given by the fact that Cond. 2 and 3 (Movement Preparation) and Cond. 7 (Control) appear to produce forgetting which is intermediate between that produced by Cond. 6 (Rest) and Cond. 5 (Active Movement). In both of these conditions there is active movement, but in each case it is less than in Cond. 5.

Pepper and Herman (1970) have examined the question of what happens to the trace of a motor act as it is forgotten, directing their attention to the effects on algebraic errors. In a number of studies on the retention of a movement extent (Adams & Dijkstra, 1966; Posner, 1967; Stelmach, 1969), Pepper and Herman find a negative time error, i.e., an undershooting, which increases with time, a finding which they account for in terms of a fading trace theory. A second finding with respect to the algebraic effect is that any interpolated material tends to result in a more positive error. The results of the present experiments support this finding. In Exp. I, a slight undershooting of about 1° is reduced to zero with interpolated material ($.05 < p < .01$, see Table 1). In Exp. II, a mean algebraic error of about $-2.5°$ is raised to between $-1°$ and $.5°$ by the interpolation of any material ($p < .05$, see Table 3). Although the large between-S differences and the many interactions make it quite clear that these are only average effects, they appear to be quite consistent. Pepper and Herman offer an explanation in terms of the distracting effects of the interpolated material.

An explanation must also be given, however, for the increase in absolute error which is found in this and other studies. The fact that the increase in absolute error is accompanied by a variance increase suggests that S is trying to match a trace which is not only "shrinking" (a less ambiguous term than "fading"), but also getting dimmer in some sense, so that it is reproduced less accurately. This suggestion is strongly supported by the effect of angles on the algebraic error, as shown in Table 2. The finding that the smaller amplitudes in a series are overestimated and the larger ones underestimated is not new; is was explored at length by Hollingworth (1909). It is likely that this represents a tendency for Ss to err toward the mean whenever they are in doubt as to the size of the angle presented, an explanation which avoids reference to a spatially extended image. This effect is obviously much stronger than any absolute "shrinkage." If it were not, we would expect the negative time error to be present for each angle taken separately, and not just for the mean of all angles.

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(Received May 8, 1972)