TEMPORAL AND SPATIAL EFFECTS OF SERIAL POSITION

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With few exceptions, research and theory concerning serial rote-learning have developed within the *S–R* connectionist tradition of Ebbinghaus, Thorndike, and Pavlov.[1] Thus, the principal explanations of serial phenomena involve the concepts of *S–R* bonds, remote associations, stimulus-traces, trace-conditioned responses, inhibition of delay, gradient of reinforcement, stimulus-generalization, intralist interference, response-competition, proactive and retroactive inhibition, etc. The various *S–R* theories as explicitly formulated all have in common the assumption that serial learning consists essentially of the acquisition of connections between items in the series, each item in turn serving as the stimulus for the anticipation of the next item. The picture is that of a chain of *S–R* connections.

According to this view, the explanation of certain serial phenomena, such as the skewed bowing of the serial-position curve, is to be sought in the nature of the *S–R* connections, either in terms of their relative strengths as affected by the interaction of excitatory and inhibitory processes that are assumed to build up in the course of learning, or by interference or response-competition between the items resulting from the formation of remote associations or from stimulus-generalization. Generally regarded by theories based on a paradigm of conditioning as one of the variables responsible for the bowed shape of the serial-position curve is the *temporal aspect* of the serial list, controlled by presenting the individual items serially in the aperture of a memory-drum at a given rate.

Purpose. The following experiments were addressed to the question of whether the occurrence of the serial-position effect depends upon a temporal serial presentation of the items or if the bowing is a more general phenomenon which may also occur when the ordering of the items is predominantly spatial rather than temporal and when *S*'s response is not limited to serial anticipation. To answer this question, four experiments were performed. In Experiment I, nine stimuli in a row were presented simultaneously; the series was predominantly *spatial*. This arrangement

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[1] A review of theories of the serial-position effect is found in J. A. McGeoch and A. L. Irion, *The Psychology of Human Learning*, 1952, 125-134.

admittedly would not rule out the possibility of temporal effects resulting from *S*'s visually scanning the stimuli in a certain order. In Experiment II there was a one-at-a-time presentation of the nine stimuli, always in one location, but there was *no* serial order. The stimuli appeared in a *random* order, except for some restrictions made for methodological reasons to be explained later. The spatial serial arrangement was in the *S*'s *response*-alternatives, which consisted of a row of nine buttons. The *S* had to learn by trail-and-error which button was associated with the particular stimulus presented at random on the screen in front of *S*. The reinforcement for pressing the correct button was the sound of a 'bong.' With this procedure, the idea of serial order probably never occurred to most of the *S*'s. In Experiments III and IV, intended as controls, the stimuli were presented in the usual temporal serial manner.

Experiment I

Subjects. All *S*s in these four experiments were upper-division and graduate students in the Department of Education. There were 30 *S*s in Experiment I. They were naïve with respect to psychological theory and experimentation. The proportion of women to men was about two to one.

Apparatus. The stimulus-items consisted of nine brightly colored simple geometric forms made of plastic.[2] The objects are 1/4 in. in thickness and approximately 1 in. in height or diameter; they appear subjectively of about equal size. The nine objects were: red triangle, green square, blue triangle, yellow diamond, red circle, yellow triangle, blue circle, pink square, and green diamond.

Procedure. *S* was first shown all the objects in a randomly scattered arrangement and was told that the objects would be arranged in a row in front of him. He would be allowed to study the order for a period of 10 sec., after which the objects would be disarranged, and *S* would be required to try to arrange them in the proper order.

Flat on the table before *S* was taped a sheet of heavy white paper, 12 × 18 in. Centered on this sheet of paper was a 1½ × 12 in. rectangle, drawn in a heavy black line; the rectangle was in a horizontal position with respect to *S*. After *E* had displayed the objects to *S* and explained the task, *E* placed a black cardboard-screen in front of *S* so as to cut off *S*'s view while the objects were arranged in a particular order within the rectangle on the sheet of paper. The objects were evenly spaced about ½ in. apart. When *E* said "Ready" and removed the screen, *S* studied the series for 10 sec. *E* then placed the screen in front of *S* and completely disarranged the objects in a haphazard manner. Then the screen was removed and *S* was told to reconstruct the order of the objects. There was no time limit, and *S* was required to guess when in doubt. If *S*'s reconstruction was not perfect (it rarely was on the first trial), the entire procedure was repeated, until *S* attained the criterion of perfect reconstruction of the serial order. After each trial, while the screen

[2] These objects are on the market as "Child Guidance Toys, No. 709, Primary Fit n' Form, Ages 1-3 yrs.," manufactured by Archer Plastics, Inc., Bronx 72, N.Y.

was in front of *S*, *E* recorded *S*'s performance. Never were *S*'s mistakes pointed out to him; he was merely told that he would have to repeat the task until he got it perfect.

A different order of items was used for every *S* that effects arising from any particular order would tend to be randomized in the over-all results. A restriction was placed on the formation of the series: no two objects of the same shape or of the same color could be adjacent to each other.

Results. The *S*s were able to learn this task quite easily. The mean num-

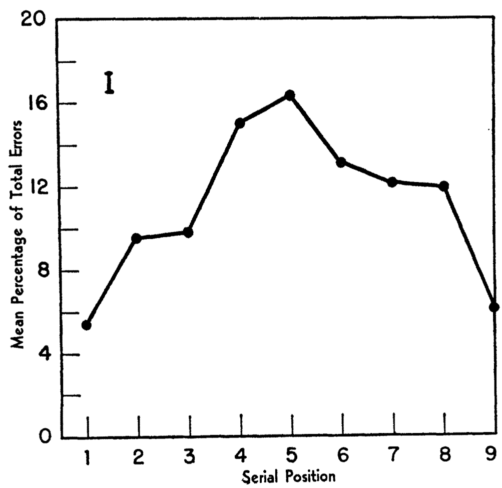

FIG. 1. THE SERIAL-POSITION CURVE IN EXPERIMENT I
The conditions were strictly spatial, *non*-temporal presentation of the serial list, with reconstruction as *S*'s mode of response.

ber of trials to criterion was only 2.96; the mean number of errors was 9.06; and the mean percentage of errors was 33.96.

Since we are primarily interested in the *shape* of the serial-position curve, rather than its absolute position on the ordinate, the curves for all these experiments are based on the percentages of total errors that occur at each position. Thus the area under all the curves is the same. The percentage of total errors at each position was determined for each *S* individually, and these percentages were then averaged for the total group. The serial-position curve thus obtained for the data of Experiment I is shown in Fig. 1. The curve is quite typical of serial-position curves obtained by temporal serial presentation of the items. This curve is however, somewhat less skewed, although the greater proportion of errors still occurs beyond the middle position.

EXPERIMENT II

Apparatus. The apparatus used in this and the following experiments is described in the Apparatus Section of this JOURNAL.[3] The aspects of the apparatus essential to this experiment were: (a) the stimulus-display unit, and (b) the response-unit. On a table directly in front of *S* was the response-unit, consisting, in this experiment, of a straight row of nine buttons. The buttons, 5/8 in. in diameter, were evenly spaced 1½ in. apart, measured from the center of the buttons. All the buttons were identical and had no labels or other distinguishing cues. Directly behind the response-unit, in full view of *S*, was the stimulus-display unit, consisting of a 3 × 4 in. screen on which the stimuli appeared. The stimuli were nine brightly colored geometric figures which appeared one at a time in the center of the screen. The figures, approximately 2 in. in size, subjectively appear about equal in size. There were three forms in each of three colors—triangles (T), squares (Sq), and circles (C) colored red (R), yellow (Y), and blue (B). The stimuli appeared on the center of the screen one at a time in an order which throughout the experiment was *random,* with two exceptions: (a) each stimulus-object appeared once within every set of nine stimuli; (b) stimuli of the same shape or color never appeared in immediate succession. The first restriction on the randomness was imposed to insure equal exposure to all stimuli; the second restriction was imposed to make the presentation of stimuli consistent with the rules for presentation in the control experiments (Experiments III and IV), except for the variations that are directly germane to the purpose of the experiments.

Procedure. Twenty-five *S*s served in the experiment. The *S* was instructed that his task was to learn by trial and error which button on the response-panel corresponds to each stimulus. When *S* pressed the correct button, he was reinforced by a 'bong,' following which the next stimulus appeared. If the wrong button was pressed, there was no 'bong,' but the next stimulus would appear. The *S* could not correct a mistake, since the instant one button was pressed, all others went 'dead,' so that pressing the correct button after an incorrect one had been pressed would produce no 'bong.' The rate of presentation of stimuli was governed by *S, i.e.* a new stimulus would not appear until *S* pressed a button, whether the right one or not. The stimulus would remain in view until the button was pressed, whereupon, after a 1-sec. delay, the next stimulus would appear. The purpose of this brief delay was to give *S* time to notice the *S–R* relationship. Also, the reinforcing 'bong' occurred while the stimulus was still in view, but the 'bong' never 'overlapped' the presentation of the next stimulus.

The response-buttons were arranged in a straight row such that the order of the stimuli to which they corresponded was the same as the serial order of the stimuli used in Experiment III, which was intended as the control for comparative purposes. Going from the *S*'s left to right, the stimulus corresponding to each button was: BSq, YT, RSq, BC, RT, YC, BT, YSq, RC.

Throughout the experiment *E* recorded *S*'s responses in *sets of nine.* The *S* had to persist in the task until he attained the criterion of nine correct responses in succession all within a *set.* The criterion was established in this manner in order to have it correspond to the criterion in the other experiments, *i.e.* correct reproduction (or anticipation) of the serial list of nine items.

[3] *Infra.,* 470-477.

Results. This trial-and-error learning was by far the most difficult of all the tasks in the four experiments. To attain criterion, *S*s required an average of 298.84 stimulus-presentations; they averaged 161.36 errors, and the mean percentage of errors was 53.98.

There was no systematic pattern in the number of errors or of correct responses made on each of the nine buttons. Individual *S*s seemed to have preferences for particular buttons and used these much more than the others; these preferences may have been determined partly by which buttons happened by chance to give *S* his first few reinforcements. For the total group, however, these positional preferences averaged out, so that all the buttons received an approximately equal number of responses. The slight, unsystematic, and non-significant differences between the total responses for each button do not in any way resemble the usual serial-position curve.

But when the *percentage* of incorrect (*i.e.* non-reinforced) responses is computed for each button, thus ruling out the effect of absolute frequency of use of the button, a serial-position effect becomes evident. In other words, the terminal buttons are learned most readily and those in the middle are learned with the greatest difficulty. To compute the points for this curve properly, the percentage of errors for each button for each *S* must first be determined. Then, so as to weight each *S* equally in the totals, the percentage of errors on each button must be divided by the total of these percentages for all nine buttons; this is done for each *S*. These percentages are then averaged over all *S*s for each button. The result is shown in Fig. 2. One point must be made clear: this curve does not represent the group's positional preferences for different buttons *per se.* It represents the relative difficulty of learning to match the buttons with their corresponding stimuli.

The data of this curve were subjected to an analysis of variance, which showed that the mean percentage of errors is significantly different for the different positions of the buttons. For the *Between Positions* main effect, $F = 3.11$, $df = 8/192$, $p < 0.01$. The most likely reason that the serial-position curve in Experiment II is so flat as compared with the other serial curves is that in the early stages of the trial-and-error learning the errors for the whole group were distributed more or less evenly over all the buttons. Such an admixture of 'random errors' in any set of serial-learning data would produce a general flattening of the serial-position curve. Also, there was greater variability in the serial-position curves of individual *S*s, due to the fact that, regardless of serial position, the button on which *S* chanced to receive his first reinforcement tended to be learned more readily than the other buttons. The fact that in trial-and-error learning *S* always hit upon his first success by chance introduced a good deal of 'random error' into the results, and therefore the serial-position curve could not possibly emerge so conspicuously as it did in all the other experiments. There is no doubt, however, that a serial-position curve bearing the es-

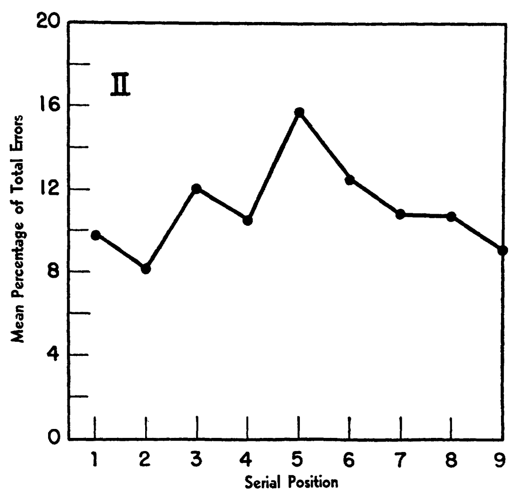

FIG. 2. THE SERIAL-POSITION CURVE IN EXPERIMENT II
The conditions were temporal, *non*-serial presentation of the stimuli, with serial spatial arrangement of the response-alternatives, and trial-and-error learning as *S*'s mode of response. See text for method of deriving the curve.

sential features was produced by a *non*-serial presentation of the stimuli and a purely spatial serial arrangement of the response-alternatives.

EXPERIMENT III

Procedure. Sixty *S*s served in the experiment. The stimuli were presented on the screen, automatically paced by the machine at a 3-sec. rate, with a 6-sec. intertrial interval between each set of nine stimuli. The stimuli were presented repeatedly in a constant serial order. The series was preceded by a small white dot in the center of the screen which served as a signal to *S* to anticipate the first item in the serial list.

S was instructed to learn the list by the method of anticipation, responding by saying 'blue square,' 'yellow triangle,' etc., and was encouraged to guess when in doubt. He was also told what stimulus-items would appear—triangles, squares, and circles colored red, blue, and yellow—and that items of the same shape or of the same color would never appear in immediate succession. The order of the stimuli was the same as the order of the response-buttons in Experiment II, viz. BSq, YT, RSq, BC, RT, YC, BT, YSq, RC. *S* began responding on the very first trial, and was required to attain the criterion of one perfect trial, *i.e.* anticipating correctly in immediate succession every item in the serial list.

Results. This experiment, which followed the usual procedure of experiments on serial learning, viz. that of presenting the items in one location in a *temporal* sequence at a constant rate, serves as a basis for comparison with the results of Experiment II, which was a strictly *spatial* type of serial learning.

Since the percentage of errors in Experiment II was 53.98 and in Experiment III was only 44.22, it is evident that *S*s in Experiment III were closer to the asymptote of complete mastery of the task than were *S*s in Experiment II, even though both groups had attained the criterion of nine successive correct responses. The degree of bowing of the serial-position curve is in part a function of the stage of learning; it becomes increasingly peaked as *S* approaches the asymptote of mastery of the list. In view of this fact, it was decided that the serial-position curves produced in Experiment II and Experiment III should be compared, not on the basis of both groups having attained the same predetermined criterion of nine successive correct responses, but rather on the basis of the groups having attained the same degree of mastery of the task as represented by the percentage of errors. In other words, though fewer errors are made in the later stages of learning, they occur increasingly in the middle positions. Thus, while the total percentage of errors continues to decrease throughout learning, the greatest relative increase in errors is in the middle positions. Therefore, it seems reasonable to compare the serial-position curves of the two groups based on the data up to the largest number of trials on which both groups have approximately the same percentage of errors.

Since Experiment III produced the smaller percentage of errors, it was possible to find a point on the learning curve for the group at which they arrived at approximately the same percentage of errors as was reached in Experiment II by the time the criterion was attained. Inspection of the data of Experiment III revealed that the group attained approximately the same percentage of errors as Experiment II at a point that included three-fourths of the trials to the criterion. Therefore, the first three-fourths of the trials for each *S* were used in determining the serial-position curve. On this basis, the percentage of errors in Experiment III was 54.08, as compared with 53.98 in Experiment II. Thus, the serial-position curves for the two experiments are based on almost exactly the same level of mastery of the tasks in terms of the percentage of errors.

The serial-position curves in Experiment III, shown in Fig. 3, were determined in the same manner as in the other experiments. The solid line in Fig. 3 is the serial-position curve based on the first three-fourths of the trials, representing the same error percentage as in Experiment II. The broken line in Fig. 3 is the serial-position curve for all the trials up to the criterion on nine successive correct trials. It is, of course, more peaked. As would be expected, the bowed curves are typical of serial-position

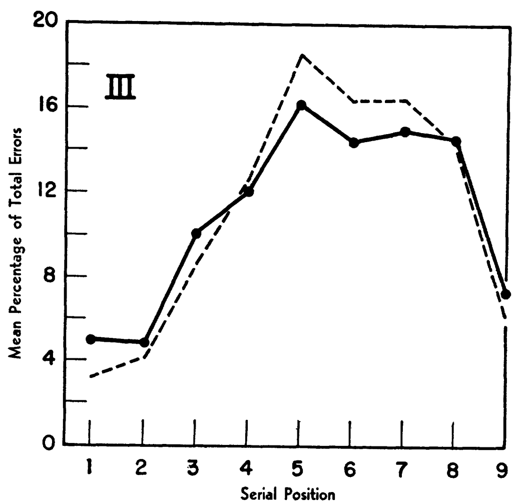

FIG. 3. THE SERIAL-POSITION CURVE IN EXPERIMENT III
The conditions were temporal serial presentation of the stimuli (machine-paced) and verbal anticipation as the mode of *S*'s response. Solid line based on first three-fourths of trials in Experiment II; Broken line, all trials in Experiment III.

curves, with the greater proportion of errors occurring past the middle position in the series.

EXPERIMENT IV

Procedure. The procedure in this experiment, in which 60 *S*s were used, was exactly the same as in Experiment III, with two exceptions: (a) the rate of presentation of the stimuli was governed by *S*; each stimulus in the series appeared only after *S* had anticipated it. Thus, *S* was under no time-pressure and could take as long as he pleased in making each response. When *S* was in doubt as to the next anticipation, he was forced to guess, since the next item would never appear until *S* made a response. (b) Twenty different orders of stimuli were used, that each order was represented only three times in the over-all results. This procedure would tend to randomize any systematic interaction between the particular stimulus-items (or their arrangement) and their position in the series.

Results. The average number of stimulus-presentations was only 27.14, the average number of errors was 8.83, and the average percentage of errors was 32.52. These figures are remarkably close to those of Experiment I, which were 26.70, 9.06, and 33.96, respectively. The *temporal* serial task appears to be of the same difficulty as the *spatial* serial task when *S* is allowed to respond at his own speed.

Since *S* began responding in Experiment IV on the very first trial with-

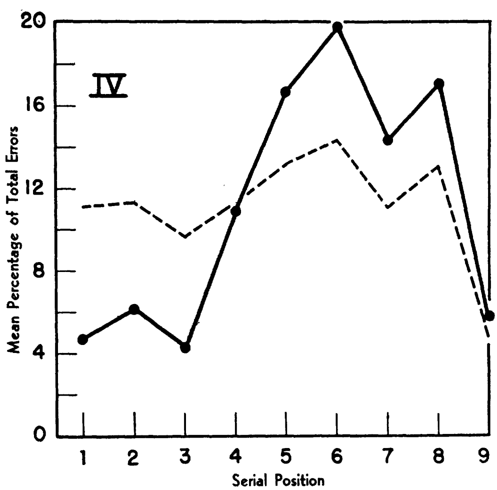

FIG. 4. THE SERIAL-POSITION CURVE IN EXPERIMENT IV

The conditions were temporal serial presentation of the stimuli (*S*-paced) and verbal anticipation as the mode of *S*'s response. Solid line, percentage of errors excluding the first trial; Broken line, percentage of errors for all trials.

out previous exposure of the serial order, the task was not comparable to Experiment I in this respect. In Experiment I *S* viewed the serial order for 10 sec. before attempting to reconstruct it on the first trial. Also, since so few trails were required to attain the criterion in Experiment IV, the first trial, which represents sheer guessing, constitutes a relatively large proportion of the total errors. Of course, the effect of serial position cannot emerge on the first trial when it is based on sheer guessing. Therefore, the serial-position curve, if it is to be properly compared with that of Experiment I, should be based only on all the errors made *after* the first trial. This was done, and the serial-position curves, shown in Fig. 4, were determined in the same manner as in the other experiments. The solid line is the curve of percentages of errors excluding the first trial. The broken line shows the percentage of errors for *all* trials. Of course, this curve is less peaked, since the errors on the first trial were more or less evenly distributed over all the positions, with the exception of the last position, which seems to show a marked 'recency' effect. Actually, of course, this low percentage of errors in the last position, especially for the first trial, is not a true 'recency' effect, but must be due to the fact that when *S* is not under time-pressure he can fairly well remember which item has not been used in the list up to the last item, which makes it easy for *S* to 'guess' correctly the last item on his very first time through the series. Another interesting feature of the solid curve is the uniformly low percentage of errors in the first three positions, which indicates that most *S*s were able to master the sequence of the first three items after just one exposure. Without time-pressure, especially, one would expect immediate memory-span to play a part in learning the serial list, and it appears that this factor is represented by the equally low percentages of errors in the first three positions.

Summary

The essential features of the serial-position curve have been shown clearly to emerge under conditions involving neither serial anticipation, nor temporal order of the stimulus-items, nor even serial order of the stimulus-items.

In Experiment I, the stimuli (nine colored geometric forms) were presented for 10 sec. on each trial in a *spatial* serial arrangement (a straight row), all the stimuli appearing simultaneously. After each 10-sec. exposure, *S* had to reconstruct, without time-limit, the serial arrangement. The errors made in reconstruction were distributed in the typical bowed curve characteristic of serial-position curves produced under the usual conditions (represented in Experiments III and IV) of temporal serial presentation with verbal anticipation as the mode of response.

In Experiment II, the stimuli (nine colored geometric forms) were presented temporally, at a *S*-paced rate, in a *random* order. The *S* had to learn to match each of a set of nine identical buttons, arranged in a row, with each of the nine stimuli. Reinforcement for pressing the button corresponding to the stimulus appearing on the screen consisted of a 'bong.' Thus, *S*'s mode of response was trial-and-error selective learning. The only *serial* aspect of the experiment was the *spatial* serial arrangement of the response-alternatives. When the percentage of errors made on each button for all trials up to the criterion of nine successive correct responses (the same criterion as in the other experiments) was determined, it was found that the relative difficulty of learning the buttons varied as a function of

their position, the easiest to learn being those at the ends and the most difficult being those in the middle. In other words, the pattern of errors had the essential features of the usual serial-position curve. It did not, however, manifest the typical skewness of most serial-position curves. The distribution of the percentages of errors on the various buttons does not reflect positional preferences *per se*. While individual *S*s showed positional preferences, reflected in the different numbers of total responses on each of the buttons, these preferences did not correspond to the serial-position curve, nor were they characteristic of the group as a whole. The total responses on each button for the group were nearly equal.

Experiments III and IV were intended as control experiments; they involved the same type of stimuli and general procedures as the other experiments, except that they maintained the essential features of temporal serial presentation and verbal anticipation on which *S–R* theories of serial rote-learning are based. In Experiment III, the stimuli were machine-paced as a 3-sec. rate, with a 6-sec. intertrial interval; in Experiment IV, the stimuli were *S*-paced, each stimulus appearing only after *S* had responded.

These findings would seem to have significance particularly for those *S–R* theories of the serial-position effect which depend upon a temporal sequence of the items and serial anticipation by *S*. The conditions of Experiments I and II, for example, completely lack the features which would permit one to invoke Lepley's hypothesis of 'trace-conditioned responses' or Hull's hypothesis of 'inhibition of delay' and its corollary that greater amounts of inhibitory potential span the middle items of the list.[4] The same can be said of Hull's theory of serial learning in 1952, which is based on the 'gradient of reinforcement,' *i.e.* the effectiveness of reinforcement in establishing an associative bond is assumed to decrease as a function of the delay in the reinforcement.[5] Yet, in Experiments I and II the conditions necessary for the operation of the variables postulated by Hull to explain the serial-position effect clearly do not exist. Still, however, the typical bowed serial-position curve comes forth. Apparently these theories of the serial-position effect either are incorrect or are not sufficiently general to explain the emergence of the bowed serial-position curve under conditions other than the learning of a temporal sequence by the method of serial anticipation.

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[4] W. M. Lepley, Serial reactions considered as conditioned reactions, *Psychol. Monogr.*, 46, 1934, No. 205, 40-45; C. L. Hull, *et al.*, *Mathematico-Deductive Theory of Rote Learning*, 1940, 110, 175-177.

[5] Hull, *A Behavior System*, 1952, 156-191.