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SERIAL ROTE-LEARNING: INCREMENTAL OR ALL-OR-NONE?*

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If the associative connections in a serial list are acquired in an all-or-none fashion, rather than gradually with every trial adding an increment of associative strength, then changing the serial order of the middle items in the list during the course of practice should have no effect on the rate of learning the list as a whole or even of the particular items that have been interchanged. Thirty subjects learned a serial list by the anticipation method. The middle items of the list were reversed in serial order approximately half-way through the number of trials required for mastery. The subjects took no longer to learn the list and made no more errors than did 30 control subjects for whom there was no change in serial order. The serial-position curves of the two groups were almost identical. It was also shown that the learning "curves" of single items in the series, when plotted for individual subjects do not reveal a gradually increasing probability of the correct response, but show instead a sudden jump on one trial from the chance guessing level to a level close to 100 per cent. correct responses. The results are consistent with a non-incremental theory of serial learning.

Introduction

Using the method of paired-associates, Rock (1957) found in two experiments that pairs presented but once before learning were learned as rapidly as those repeated until they were learned. Replicating Rock's experiments with additional controls, Clark, Lansford, and Dallenbach (1960) corroborated Rock's results. It appears from these experiments that repetition plays no role in the formation of associations other than that of providing the occasion for new associations to be formed on a single trial. Within the framework of the prevailing theories of learning stemming from Ebbinghaus, Pavlov, Thorndike, and Hull, this is a radical hypothesis that demands further investigation. Indeed, the idea that learning is a gradual process, with each repetition or reinforcement of an S-R event adding an increment of associative strength, has been, until Rock's findings, one of the least questioned assumptions underlying S-R conceptions of the nature of learning.

The present experiment was intended to test the hypothesis, originally suggested by Bolles (1959) that a subject, in learning a serial list by the anticipation method, does not acquire an increment of associative strength for all the S-R associations in the series with every trial. The usual theoretical explanations of serial learning phenomena, such as Hull's theory (Hull *et al.*, 1940), assume that the associative strength between the items in the series increases by gradual increments on every trial and that the greater difficulty in learning the middle items, as evinced by the bow-shaped serial-position curve, is the result of inhibition that accumulates in the middle of the list. An alternative to this traditional "incremental" or "continuity" theory is the notion that the subject learns each item in the series in an all-or-none fashion on a single trial, while on that particular trial the as yet not learned items do not gain an iota in associative strength. The serial-position effect would then be attributable simply to the order in which the subject learns the items in this all-or-none fashion. The beginning and end of the list generally are learned first and the

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middle items are learned last. Thus, according to this view, the S-R connections in the middle of the list should not acquire any associative strength until late in learning, so that even if the order of these middle items were reversed during the early learning trials, nothing should be lost and the subject should learn the serial list in the same number of trials as if there had been no change in the serial order.

The only experimental tests of this prediction were performed by Bolles (1959), who found that interchanging the fourth and sixth items in a nine-item list one-third of the way through learning had no significant effect on mean trials for learning or on the shape of the serial-position curve, as compared with the control conditions in which there was no change in serial order. Bolles concluded that serial learning follows non-continuity principles and that the associative strength necessary for performance is acquired in one trial.

An important theoretical point such as this one indeed requires more than a single experimental test, especially in this case, since Bolles's experiments and their analysis leave something to be desired in terms of experimental procedure. Bolles's two experiments used only eight and six subjects, respectively, and the window of the memory drum had to be moved in the course of learning to reveal the changed list, a procedure that could have alerted subjects to the changed conditions. That the same manipulation prevailed in the control condition is not an adequate safeguard.

The present experiment was designed as a more stringent test of the non-continuity hypothesis with regard to serial learning. Since learning a list of nonsense syllables consists of two phases—(1) learning the items that compose the list, and (2) learning their serial order—and since here we wish to test the non-continuity hypothesis only with respect to the *serial* learning phase, this experiment used, instead of nonsense syllables, coloured geometric forms with which the subjects were made familiar before having to learn their serial order. The interchange of the fifth and sixth items in a 10-item series occurred without any manipulation of the apparatus or any delay between trials. The interchange occurred on the same trial for all subjects in the experimental group. The change trial (Trial 7) was set, on the basis of previous tests with similar subjects, at approximately the average half-way point in learning. A constant serial order was used for all subjects, so that any irregularities in the shape of the serial position curve for one particular order of stimuli would not be "averaged out"; if learning was not incremental, the experimental condition should have no effect and the serial-position curves of experimental and control groups would be expected to manifest the same general irregularities. Also, the data of the present experiment are based on a much larger sample of subjects than Bolles used, and they were subjected to a more detailed, trial-by-trial, statistical analysis.

Method

Subjects. Sixty-three students were recruited from an introductory course in educational psychology. All were naive to serial learning experiments. The records of three subjects were eliminated from the analysis: one subject in the Experimental Group was emotionally upset by the task and quit before attaining the criterion of mastery; another subject in the Experimental Group mastered the entire list before the change trial; and one subject in the Control Group, having failed to show any appreciable learning in 40 trials, was dismissed. The Experimental and Control Groups each had 30 subjects.

Apparatus. The stimuli, consisting of triangles (T), squares (S), and circles (C), coloured red (R), yellow (Y), blue (B), and white (W) were projected on a screen by an automatic device which has been described in detail elsewhere (Jensen *et al.*, 1962). The subject sat approximately 3 ft. from the screen. The stimuli, $2\frac{1}{2}$ in. in size on the screen and of vivid colour, were projected at a 3-sec. rate with a 6-sec. intertrial interval. The series was always preceded by a green light that appeared at the bottom of the screen as the signal for the subject to anticipate the first item in the series.

Procedure. All subjects were instructed that they would have to learn, by the anticipation method, the serial order of ten different coloured forms, consisting of triangles, squares, and circles coloured red, yellow, blue, and white. They were informed that no item would be repeated in the series and that the same colour or shape would never be adjacent in the series. These instructions are such that subjects are able to name all the stimuli in the series before the first presentation, so that they could be required to make their first anticipations by sheer guessing on the very first trial. Subjects responded by saying "red square," "white circle," etc. This procedure minimizes the response learning phase of the task so that practically all the subject has to learn is the *serial order* of the items. The aim of the experiment was never mentioned to the subjects and, of course, there was no hint in any respect of the procedure that the serial order was to be changed in the course of learning for half the subjects. All subjects were requires to learn the list to the criterion of mastery, i.e. one trial with correct anticipation of every item.

Control condition. The serial order for the Control Group throughout all trials was: (green light), RS, WC, YT, BS, YC, RT, WS, RC, WT, BC.

Experimental condition. For the first six trials the serial order was: (green light), RS, WC, YT, BS, *RT*, *YC*, WS, RC, WT, BC. On Trial 7 Items 5 and 6 were interchanged, so that the order for all succeeding trials was exactly the same as the Control condition, thus: (green light), RS, WC, YT, BS, *YC*, *RT*, WS, RC, WT, BC.

It should be pointed out that to test the hypothesis under consideration does not require any more complex design that that employed here. Nothing would be gained, for example, by counterbalancing the order of the items in Positions 5 and 6 in another pair of Experimental and Control groups. Since both groups in the present design learn the *same* serial order after Trial 6, it does not matter if the ease of learning the sequence *RT-YC* is different from that of *YC-RT*. In any case, according to the incremental theory of learning, the Experimental Group after Trial 6 should be at a disadvantage as compared with the Control Group.

Results

In brief, there were no detectable statistically significant differences between the performances of the Experimental and Control Groups. The data were analysed separately for the Before Change and After Change trials. Table I presents the mean trials, errors, and per cent. errors and their standard deviations (SD) in both stages of learning. Contrary to the prediction from continuity theory, the Control Group actually took slightly more trials to learn and made more errors than did the Experimental Group. The mean errors in Positions 5 + 6, i.e. the interchanged items, were

TABLE I

Mean Number of Trials, Errors, and Percentage of Errors* Before and After Serial-Order Change

	Before change: Trials 1–6			*After change: Trials 7–Criterion*		
	Experimental	*Control*	*Difference*	*Experimental*	*Control*	*Difference*
Mean trials ..	(6)	(6)	—	9·20	9·33	− 0·13
SD ..	(0)	(0)	—	4·63	4·30	—
Mean errors ..	37·33	38·20	− 0·87	32·93	33·03	− 0·10
SD ..	7·17	6·47	—	20·57	16·47	—
Mean per cent. Errors ..	62.23	63·68	− 1·45	33·93	35·44	− 1·51
SD ..	11·95	10·79	—	9·63	11·80	—

$$* \text{ Percentage of errors} = \frac{100 \times \text{incorrect responses}}{\text{correct} + \text{incorrect responses}}$$

19·5 and 19·9 for the Experimental and Control Groups, respectively. All of the differences between the Experimental and Control Group, both in means and *SD*s, are minute and statistically non-significant.

It should be noted that the total number of trials required to attain mastery was, on the average, approximately 15 trials. Thus, the serial order change on Trial 7 came, on the average, slightly less than half-way to the criterion of mastery.

TABLE II

LEARNING CURVE AT SERIAL POSITION 5

Trial	*Number correct*		*Number of subjects*		*Per cent. correct*		χ^{2}*	$P \geq$
	Experimental	*Control*	*Experimental*	*Control*	*Experimental*	*Control*		
1	2	1	30	30	6·67	3·33	0·00	1·00
2	5	3	30	30	16·67	10·00	0·14	0·69
3	5	2	30	30	16.67	6.67	0·65	0·42
4	8	3	30	30	26.67	10·00	1·78	0·19
5	11	4	30	30	36·67	13·33	3·20	0·07
6	2	7	30	30	6·67	23·33	2·09	0·16
7	5	4	30	30	16·67	13·33	0·00	1·00
8	5	6	28	29	17·86	20·69	0·08	0·76
9	7	3	27	29	25.93	10·43	1·37	0·23
10	7	13	27	29	25·93	44·83	1·43	0·23
11	5	7	27	29	18·52	24·14	0·35	0·55
12	8	10	25	26	32·00	38·47	0·04	0·92
13	10	11	22	25	45·45	44·00	0·00	1·00
14	5	10	20	22	25·00	45·45	1·12	0·31
15	10	12	16	20	62·50	60·00	0·00	1·00
16	7	12	11	16	63·64	75·00	0·04	0·84
17	3	9	9	11	33·33	81·32	**	< 0·10
18	5	5	7	9	71·43	55·56	—	n.s.
19	5	5	6	8	83·33	62·50	—	n.s.
20	2	3	5	6	40·00	50·00	—	n.s.
21	1	2	3	6	33·33	33·33	—	n.s.
22	0	1	3	4	0·00	25·00	—	n.s.
23	1	1	3	2	33·33	50·00	—	n.s.
24	1	1	2	2	50·00	50·00	—	n.s.
25	0	1	1	1	0·00	1·00	—	n.s.
26	1	—	1	0	100·00	—	—	—
27	0	—	1	0	0·00	—	—	—
28	0	—	1	0	0·00	—	—	—

* Chi square with Yates's correction.

** Beyond this point Fisher's exact probability test was used (Siegel, 1956, pp. 96–100). Probabilities greater than 0·10 are indicated as non-significant (n.s.).

The serial-position curves of the Experimental and Control Groups are almost indistinguishable. This is true also when the curves are plotted separately for Trials 1–6 and for the trials after the reversal (7–criterion). The intraclass correlation (Haggard, 1958) may be regarded as an index, ranging from − 1·00 to + 1·00, of the degree of similarity between the serial-position curves of the Experimental and Control Groups. The intraclass correlation between the curves based on the trials before the change is 0·97; for the trials after the change it is 0·99.

Tables II and III present the "learning curves" for the reversed positions (5 and 6) for each group throughout the entire course of learning. The point of serial reversal is indicated by the line after Trial 6. The significance of the difference between the groups in per cent. of correct responses on each trial was tested by chi-square up to Trial 17. In the trials from 17 on, the frequencies were too small for the valid use of chi-square and the Fisher exact probability test was used (Siegel, 1956, pp, 96–101). The two-tailed probabilities of the obtained chi-squares (taken from Table VI in Kelley, 1948, p. 202) reveal no significant differences (taking the traditional $p < 0.05$ as "significant") between the two groups on any trial. Also, a chi-square test of the difference between the groups in going from Trial 6 to Trial 7 (the change trial) revealed no significant difference at either Position 5 or 6.

TABLE III

LEARNING CURVE AT SERIAL POSITION 6

Trial	Number correct		Number of subjects		Per cent. correct		χ^{2*}	$P \geq$
	Experimental	Control	Experimental	Control	Experimental	Control		
1	5	3	30	30	16·67	10·00	0·14	0·69
2	4	7	30	30	13·33	23·33	0·45	0·48
3	4	7	30	30	13·33	23·33	0·45	0·48
4	8	6	30	30	26·67	20·00	0·09	0·76
5	9	11	30	30	30·00	36·67	0·08	0·76
6	8	15	30	30	26·67	50.00	2·54	0·11
7	10	8	30	30	33·33	26·67	1·07	0·31
8	17	12	28	29	60·72	41·38	1·43	0·23
9	15	15	27	29	55·56	51·73	0·00	1·00
10	14	17	27	29	51·86	58.63	0·06	0·84
11	19	19	27	29	70·38	65·52	0·01	0·92
12	17	16	25	26	68·00	61·54	0·04	0·84
13	13	18	22	25	59·10	72·00	0·39	0·54
14	12	16	20	22	60·00	72·73	0·30	0·61
15	11	18	16	20	68·75	90·00	1·39	0·23
16	6	14	11	16	54·55	87·50	2·17	0·13
17	6	10	9	11	66.67	90·91	**	n.s.
18	6	8	7	9	85·72	88·89	—	n.s.
19	6	3	6	8	100·00	37·50	—	n.s.
20	3	5	5	6	60.00	83·33	—	n.s.
21	3	2	3	6	100·00	33·33	—	n.s.
22	2	3	3	4	66·67	75·00	—	n.s.
23	2	1	3	2	66·67	50·00	—	n.s.
24	1	1	2	2	50·00	50·00	—	n.s.
25	0	0	1	1	0·00	0·00	—	n.s.
26	0	—	1	0	0·00	—	—	—
27	1	—	1	0	100·00	—	—	—
28	0	—	1	0	0·00	—	—	—

* Chi aquare with Yates's correction.

** Beyond this point Fisher's exact probability test was used (Siegel, 1956, pp. 96–100). Probabilities greater than 0·10 are indicated as non-significant (n.s.).

Only one of the 30 subjects in the Experimental Group expressed any doubt at the end of the experiment that the serial order had remained constant throughout all the trials. This subject attained criterion in only eight trials and remarked to the experimenter that she had the feeling that the list had changed at some time, but she was not certain. Subjects were never directly questioned on this matter, since the object of the experiment, of course, had to be kept secret. However, several psychologically sophisticated subjects (research assistants and one professor), who were not included in the experiment proper, were tested and questioned about the change. None was at all aware of the change and all expressed surprise when informed of it.

Supplementary data

If learning the serial position of each item takes place on a single trial for each item, as suggested by the present experiment, the "learning curve" for single items theoretically should show a sudden jump from a probability of zero for making a

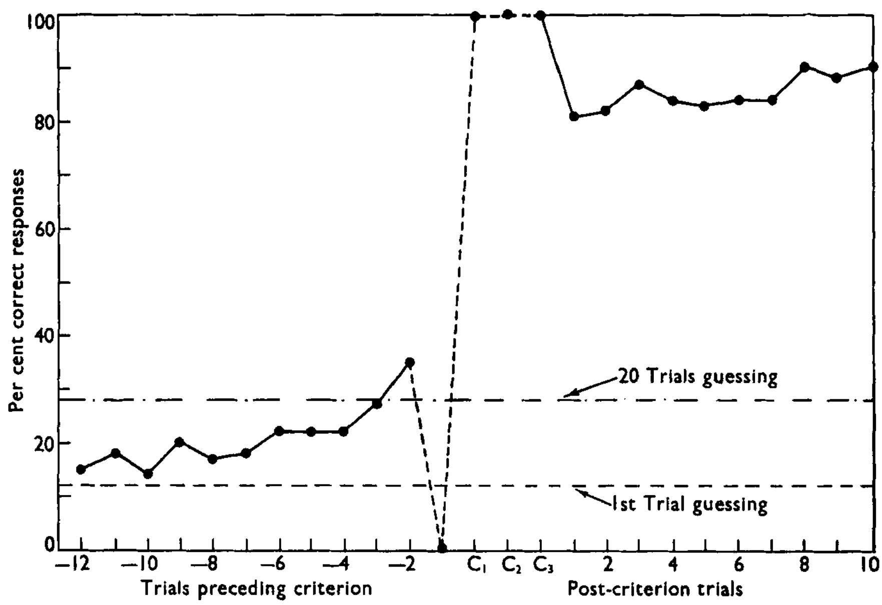

FIGURE 1

A backward learning curve, showing the mean percentage of correct reponses on each item in the serial list among a group of 60 subjects on the 12 trials preceding the criterion of three successive correct trials.

correct response to 100 per cent. correct responses. In learning the serial order of items that are already familiar to the subject, as in the present experiment, the learning curve should jump from the chance guessing level to approximately 100 per cent. correct responses, but it will always be slightly less than 100 per cent. since some subjects will attain the criterion of learning merely by chance guessing.

To determine the probability of making a correct response as a function of number of learning trials, further data were obtained using the same form of serial learning as in the previous experiment. The subjects (60 university students) learned by the anticipation method a nine-item serial list composed of triangles, squares, and circles coloured red, yellow, and blue. The procedure was approximately the same as for the previous experiment. Subjects were informed that items of the same shape or colour would never be adjacent in the series. The stimuli were projected one at a time on a screen at a 3-sec. rate with a 6-sec. intertrial interval. All subjects learned to a criterion of three successive perfect trials.

A backward learning curve (Hayes, 1953) was obtained for each item in the list. These "curves" are plotted backward from the trial on which the subject attained the criterion, which consisted of anticipating the item correctly on three successive trials. The backward curves were then averaged for all items. The resultant mean curve is shown in Figure 1, which represents the percentage of correct responses made by all subjects on the 12 trials preceding the criterion. The -1 Trial shows the last error made before attaining the criterion of three successive correct responses (C_1, C_2, C_3).

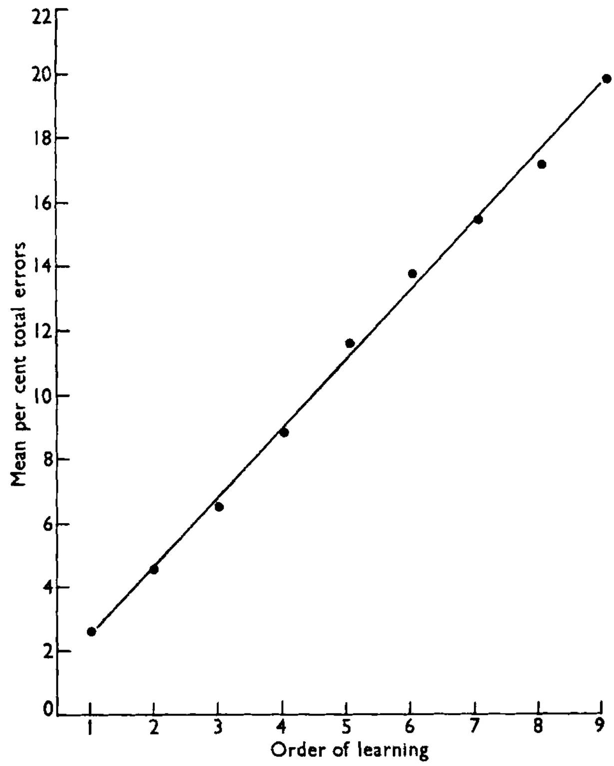

FIGURE 2

Mean percentage of errors on each item plotted in the order (determined for each subject) in which each item in the serial list was learned to a criterion of three successive correct trials. ($N = 60$).

The post-criterion trials show the usual drop. The "20 trials guessing" line indicates the mean percentage of correct responses made by a control group of 20 subjects who were presented with a different serial order of the items on each of twenty trials and for whom every anticipation was necessarily a sheer guess. These subjects knew the items composing the lists and they knew the rules that adjacent items would never be of the same shape or colour. The "first trial guessing" indicates the mean percentage of correct responses made by all subjects on the first trial, which consisted of sheer guessing. This level is lower than the mean for guessing 20 trials because of a greater number of omissions on the first trial. Only at the -2 trial did the percentage correct rise above the level of chance guessing. This may have been because for some subjects an association was actually learned the first or second time the item was anticipated correctly and the criterion of three correct responses was too stringent.

This criterion of learning seemed necessary, however, because of the relatively high chance probability of guessing a correct response. The important point is that there is not a significant increase above a chance level in the probability of a correct response on the several trials preceding the criterion.

This phenomenon brings into consideration two different theoretical interpretations. If the learning is a gradual process, with every trial adding an increment to the associative strength for the correct response, there must be a performance threshold which is attained before the learning is manifest. Furthermore, there must be practically no oscillation of associative strength before the threshold is attained. Yet the post-criterion drop would seem to indicate the presence of oscillation. What seems to be a simpler interpretation is that each connection in the serial list is learned on one trial in an all-or-none fashion. Until the connection has been learned on one particular trial, the probability of anticipating the correct item is not above the chance level.

The percentage of total errors that occurred at each serial position during the course of learning up to the criterion of mastery of the whole list was determined for each subject. These percentages for each subject were arranged in the order in which the corresponding items were learned to a criterion of three successive correct trials; the percentages were then averaged for the entire groups of 60 subjects. The result is shown in Figure 2, which clearly indicates that the increment in difficulty in each successive item learned is a *constant proportion* of the total difficulty of learning the list as a whole. In terms of the "one-trial learning" hypothesis, Figure 2 can be interpreted as indicating that all connections in the list are of *equal* relative difficulty. Since the subject cannot learn the whole list on one trial, he must learn the connections in a particular order over a number of trials. The number of trials required to learn each connection once the previous connection has been learned is equal for all connections.

The "bow-shaped" serial-position curve is reflected in the high degree of agreement among subjects in the *order* in which they learn these serial connections. When the connections are ranked for each subject in the order in which each connection was learned to a criterion of three successive correct trials, the modal order is:—

Serial Position:	1	2	3	4	5	6	7	8	9
Order of Learning:	1	2	4	6	8	9	7	5	3

As a measure of agreement among subjects in the order of learning the connections, Kendall's coefficient of concordance W was computed and was found to be 0·69. The cause of this high degree of unanimity in the order of learning is not yet known.

Discussion

The results of the present experiments are essentially the same as those found by Bolles (1959). But these results, taken by themselves, are only *consistent* with a non-continuity theory of serial learning. They do not *prove* the theory. Hull's continuity-type theory, which explains the greater difficulty in learning the middle of the list as a result of the accumulation of inhibitory tendencies, is capable of interpreting the results of the present experiment and of Bolles's experiment. If inhibition gradually builds up on the middle S-R connection (Positions 5–6), which would normally oppose the subject's correct performance on these items until late in learning when the associative strength has gown sufficiently to overcome the inhibitory tendency, and then, if, in the course of practice, a new S-R connection (say, 6–5) were put into the list to replace the connection that had already accumulated inhibitory tendencies, the inhibition attached to the original S-R connection would be diminished or eliminated.

Since a part of the series would already have been learned, not so much inhibition would accrue to the new S-R connection and the remaining task would be as easy or possibly even easier, to learn as if the list had remained unchanged throughout all the trials. But this is mere wishful thinking along Hullian lines, for there is no independent support of Hull's notion that there is a greater inhibitory potential in the middle of the series. Thus, the results of the present experiments would seem to further weaken the continuity of incremental hypothesis and lend support to the all-or-none theory of serial learning. The writer has discussed elsewhere (Jensen, 1962), the broad implications of these findings for a theory of serial learning.

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