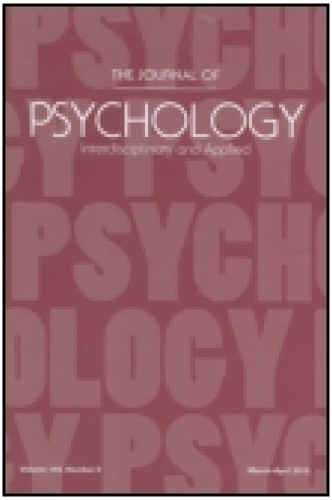

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AN EMPIRICAL THEORY OF THE SERIAL-POSITION EFFECT*

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A. INTRODUCTION

In rote-learning a list of nonsense syllables or other relatively homogeneous items, the errors made before mastery are distributed according to the positions of the items in the series, forming the classical, negatively skewed, bow-shaped serial-position curve. The problem of explaining this curve has long occupied learning theorists, but no satisfactory theory has yet emerged.

The facts and theories of serial learning have been reviewed by McGeoch and Irion (9). Some of the important facts that must be accounted for by a theory of serial learning are the following: (*a*) factors affecting the overall difficulty of the learning task, such as familiarity of the items and distribution of practice, do not much affect the *relative* difficulty at each position, i.e., all serial-position curves for a list of a given length are extremely similar when plotted in terms of the *percentage* of total errors at each position (8); (*b*) individual differences in learning ability and factors (e.g., anxiety) which affect learning rate and memory span, affect the degree of skewness more than the degree of bowing of the serial-position curve (9, pp. 124-125); (*c*) the degree of skewness decreases as the number of items in the list increases; (*d*) a continuous list in which the temporal separation between the last item and the first item is the same as the separation between other items in the list produces a flatter bow-shaped serial-position curve than when there is a temporal gap between presentations of the list (3).

1. *An Empirical Theory*

The purpose of this paper is to present an empirical theory of the serial-position effect, along with some supporting evidence. The theory is called "empirical" because it is derived largely from experimental findings and is not based on assumptions or postulates having little or no empirical

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foundation. It is not offered as a highly formal theory or as a final finished product, but as an heuristic hypothesis that opens the way for further investigation.

The shape of the serial-position curve would seem to be a consequence of the following conditions:

a. The number of items or responses to be learned in the serial list is greater than the subject's (*S*'s) immediate memory span, which is the length of list he can learn in one trial. Consequently, the *S* requires more than one trial or exposure in order to learn the list. Without this condition, there can be no serial-position curve.

b. If the *S* cannot learn all the items on one trial, he must learn some items before he learns others; this implies that the items must be learned in in some *order*.

c. The first item learned is usually the first item to which the *S* attends or to which the *S* makes some response. This item is usually the first one presented in the serial list. It may be regarded as the *anchor* item.

d. If it is assumed that the *S* learns most readily by "attaching" new responses to previously learned responses, the *S* should learn the serial list around the anchor item, both in a forward and in a backward direction. The anchor serves as a cue for other responses in the series. The basic assumption is that it is easier to learn an unfamiliar item that is adjacent to an item that has already been learned than it is to learn an unfamiliar item that is presented among other items not yet learned.

e. If this is true, the serial list should be learned (when learning is by the usual anticipation method) in a certain order around the anchor point. Take, for example, a 9-item serial list. Say our hypothetical *S* learns one item on every trial; the first item is established as the anchor position on the first trial. On the second trial he will learn Item 2, on the third trial Item 9, and so on. Thus, the order of learning will be around the anchor point as follows:

Serial position:	6	7	8	9	$\underline{\underline{1}}$	2	3	4	5
Order of learning:	9	7	5	3	$\underline{\underline{1}}$	2	4	6	8

Or:

Serial position:	1	2	3	4	5	6	7	8	9
Order of learning:	1	2	4	6	8	9	7	5	3

f. An additional assumption, which is already well-supported by empirical evidence, applies to serial lists of fewer than seven or eight items. For such short lists, the first two or three items are learned in a single trial. This is probably due to the fact that in a short list, which is just three or four items longer than the *S*'s immediate memory span, there is not so much retroactive interference from the last two or three items in the list to "inhibit" the *S*'s retention of the first few items which fall within the *S*'s memory span. Thus, for a 7-item list, the order of learning would be:

Serial position:	1	2	3	4	5	6	7
Order of learning:	1	2	3	5	7	6	4

And for a 6-item list the order would be:

Serial position:	1	2	3	4	5	6
Order of learning:	1	2	3	5	6	4

Consequently, the shorter the list, the more skewed the serial-position curve. The curves for long serial lists would appear almost symmetrical.

g. If it is assumed that the number of trials required by the *S* to learn the serial list is equally divided among the items in the series, and if each item is learned on one trial in an all-or-none fashion, the proportion of the total errors made at each position up to the trial of mastery of the whole list should be equal to the number of the rank order in which that position is learned divided by $1 + 2 \ldots + N$, where N is the number of positions in the series. For example, the percentage of total errors made at each position in a 10-item series learned to a criterion of mastery would be:

Serial Position:	1	2	3	4	5	6	7	8	9	10
Order of learning:	1	2	4	6	8	10	9	7	5	3
Percentage errors:	1.82	3.64	7.27	10.91	14.55	18.18	16.36	12.73	9.09	5.45

The average serial-position curve for a *group* of *S*s is usually flatter and more bow-shaped than the almost triangular-shaped curve predicted by the theory. The reason for this is that the group curve actually does not represent the curve for individual *S*s. Since there is not perfect unanimity among *S*s in the order in which items are learned, though the degree of agreement is indeed high, the group curve appears to be a "smoothed" version of the curve predicted by the theory. The theory is "probabilistic" in the sense that it only predicts the most probable order of learning the items. Because of the many idiosyncratic factors that affect a given *S*'s performance, there are slight variations in the order of learning; certain items will tend, because of idiosyncratic associations, to become secondary anchor points in the series. And for lists that are learned in just a few trials, the characteristic oscillations in performance from trial to trial can considerably affect the degree of irregularity of those aspects of the data from which we determine the rank order in which the *S* learned the items, viz., the number of errors at each position or the number of trials preceding a given criterion of learning for each position. The theory, therefore, predicts that differences in the degree of bowing of group serial-position curves are caused by differences among the groups in the degree of within-group agreement in the order of learning. Thus, a relatively flat serial-position curve would result from relatively low agreement among *S*s in the order of learning, while a very peaked curve would indicate high agreement among *S*s in the order of learning the items. Differences in skewness, on the other hand, would be related to conditions which affect memory span.

B. METHOD

1. *Subjects*

The *S*s were 245 university students recruited from an introductory course in educational psychology. There were approximately twice as many women as men.

2. *Procedure*

Learning a list of nonsense syllables or other verbal materials generally involves two phases: (*a*) the acquisition of the syllables; and (*b*) the learning of their serial order. In order to minimize the first phase, since we wished to study mainly the *serial* learning, the present experiments used as stimuli colored geometric forms: triangles, squares and circles colored red, yellow, blue, and white. Nine- and ten-item lists were composed of these stimuli. Two rules governed the formation of lists: (*a*) no item would appear more than once in the list; and (*b*) items of the same shape or color would never be adjacent in the series. Before the serial learning task was presented, the *S* always knew perfectly the items composing the list. The stimuli were projected one at a time on a screen at rates varying in different experiments from two to four seconds per stimulus, with intertrial intervals of from four to eight seconds. A technical description of the apparatus is presented elsewhere (6). *S*s learned by the anticipation method, responding by saying "red triangle," etc. They were encouraged to guess when in doubt as to the correct response on subsequent trials. *S*s learned to a criterion of mastery of the whole list.

C. RESULTS

Only those aspects of the data directly relevant to the proposed theory of the serial-position effect are presented.

1. *Evidence of the One-Trial Nature of Serial Learning*

A backward learning curve (4), showing the twelve trials preceding the criterion of mastery was plotted for the last position learned in the series by each of 200 *S*s. The last item learned was defined as the item on which the last error was made before mastery of the whole list; in the case of ties, the item closest to the middle of the series was selected. The backward "curve" is shown in Figure 1, which clearly indicates that there was no significant rise above a chance level in the correct responses among the 200 *S*s on the several trials before the criterion was attained. Backward curves plotted in the same manner for each position in the series, with criterion of learning for each position being three successive correct responses, are essentially identical to Figure 1. To determine the chance percentage of correct responses that could be obtained by sheer guessing, 20 *S*s were forced to guess for 20 trials, with a different serial order on every trial. The mean percentage correct by sheer guessing was 28.30 per cent. These results indicate a sudden, rather than a gradual, learning of the serial position of the individual items.

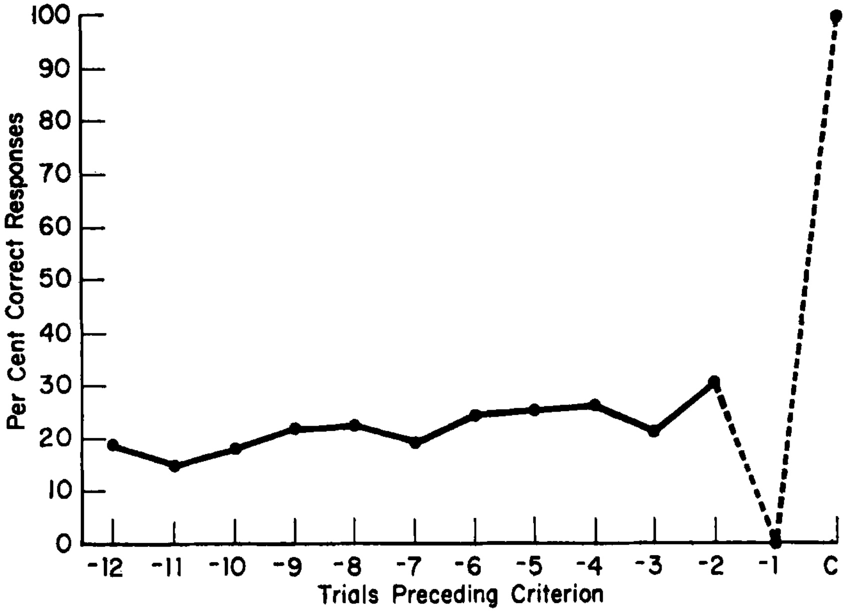

FIGURE 1

A backward learning curve for the last item learned, showing the percentage of correct responses among 200 *S*s on each of the 12 trials preceding the criterion of mastery.

The percentage of errors made at each position up to the trial at which the item had been anticipated correctly on three successive trials is at least as great as the percentage of errors obtained under conditions of chance guessing. For 60 *S*s who learned a nine-item list at a four-second rate with an eight-second intertrial interval, the percentage of errors at each position up to the criterion trial for that position was:

Position:	1	2	3	4	5	6	7	8	9
Per cent errors:	81	79	84	78	82	83	85	82	81

The mean percentage of errors was 81.74. The mean percentage of errors on the very first trial, which represented sheer guessing, was 79.75 per cent. Thus, these results substantiate the impression that no learning was manifest at a given position up to the trial on which the item in that position attained the criterion of learning. The rather stringent criterion of three successive correct responses was needed to distinguish *learned* correct responses from correct responses that might be due to chance.

2. *The S-R Contingencies in Serial Learning*

S-R theories generally picture serial learning as consisting of the formation of a chain of S-R bonds (e.g., 5), each response in turn serving as a partial stimulus or cue for the succeeding response. If this were true, and if the learning consists of a gradual or continuous strengthening of S-R bonds on every trial, one should predict a positive correlation between anticipating one item in the series correctly and the probability of anticipating correctly the item immediately following. A correct response would act as a valid cue for the next response so that the probability of its being correct should be greater than it would be if the preceding response were incorrect.

To investigate this correlation, 2 × 2 chi-square contingency tables were made up for every successive pair of items in the series, i.e., 1-2, 2-3, 3-4, . . . 8-9. For example, the contingency between positions 4 and 5 is:

		Position 4	
		−	+
Position 5	+	5	8
	−	14	23

$\chi^2 = .002$

The cell entries were based on the first trial on which each of 60 *S*s made four correct responses on a 9-item list. (Only 50 *S*s in this group had a trial with exactly four correct responses.) Another set of contingency tables was based on the first trial on which each *S* made five correct responses. (Only 54 *S*s had a trial with exactly five correct responses.) There were 16 contingency tables in all. Of these 16 contingencies, only four yielded chi-squares large enough to be significant at the 5 per cent level, and of these only three were in the predicted direction. The highest degree of correlation for any of the contingencies is represented by a phi coefficient of .16. It may thus be concluded that the correlation between successive serial responses on any given trial is negligible.

This fact seems surprising in view of the traditional S-R theories of serial learning, which assume an incremental, rather than an all-or-none, growth in associative strength between items. The interesting and highly important point, however, is that these findings are perfectly consistent with a one-trial, all-or-none conception of learning. If the *S* responds at a strictly chance level at each position until on one trial the item in a particular position is learned, there should be a zero correlation on any one trial between whether or not a response is correct and whether or not the immediately succeeding response is correct. This actually seems to be case.

3. *The Relative Difficulty of Learning Each Position*

The percentage of total errors that occurred at each serial position during the course of learning a 9-item list (stimuli presented at a two-second rate with a four-second intertrial interval) up to a criterion of three successive perfect repetitions of the whole list was determined for each *S* ($N = 60$). These percentages for each *S* 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 group of 60 *S*s. As can be seen in Figure 2, the increment in percentage of errors for each successive item learned is a *constant proportion* of the total errors made in learning the entire list. An analysis of variance showed that the points in Figure 2 do not depart significantly from the straight line, which was drawn to the closest fit of the data points. The same straight line would result if instead of errors we had used the number of trials taken to learn each item. The correlation (Pearson r) between errors and number of trials to criterion was .92. If we assume that items are learned in an all-or-none fashion, Figure 2 may be interpreted as indicating that, for a given *S*, every item in the series takes as many trials to be learned as every other item, once the previous items in the order of learning have been learned.

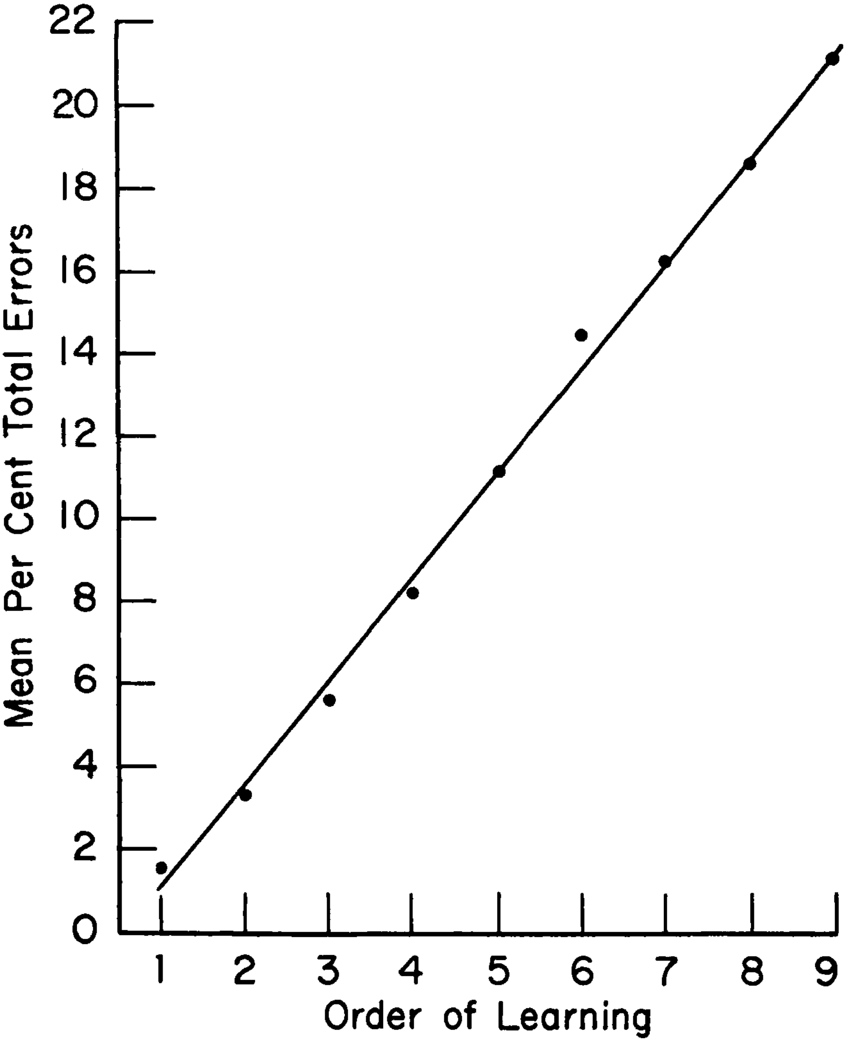

FIGURE 2

Mean percentage of errors on each item plotted in the order (determined for each *S*) in which each item in the 9-item serial list was learned to a criterion of three successive correct trials. ($N = 60$). The straight line is drawn to the best fit.

Figure 3 was obtained in the same manner as Figure 2; it is based on 25 *S*s who had learned a 10-item list to a criterion of mastery, with a three-second rate of presentation and a six-second intertrial interval. In

Figure 3, however, the straight line represents the points that would be predicted by the theory, as explained in the Introduction (p. 129). The line falls on the points 1/55, 2/55, 3/55 . . . 10/55. (These fractions were converted to percentages in Figure 3.) The actual data points fall very close to the straight line called for by our theory.

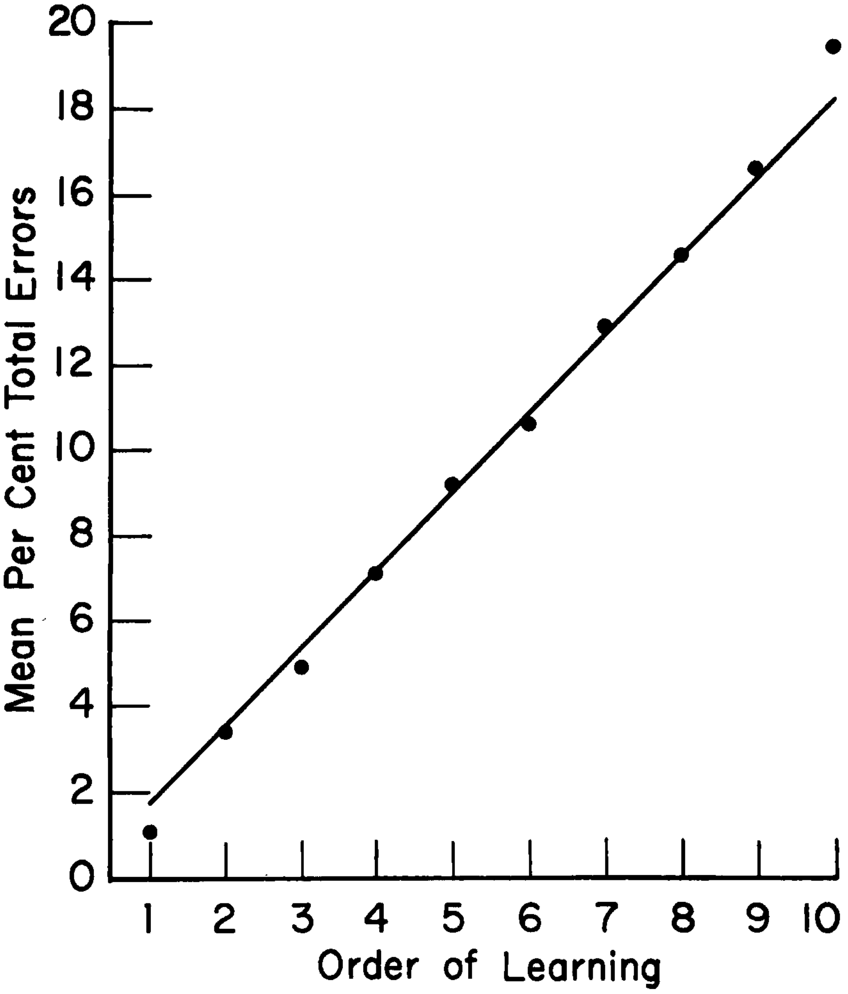

FIGURE 3

Mean percentage of errors on each item plotted in the order (determined for each *S*) in which each item in the 10-item serial list was learned to a criterion of mastery (one perfect trial). ($N = 25$). The straight line is called for by the theory.

4. *Order of Learning*

The hypothesis concerning the order of learning is based on theoretical and empirical considerations. It is held to be easier to learn new responses when they are adjacent to known, established, or anchored responses, and therefore the *S* learns the serial list around the first-learned item, which is usually the first item in the serial list. As yet we have no independent experimental evidence of the validity of this assumption, which is presently under investigation in our laboratory. Therefore it is the one element of the theory which at this stage has strictly the status of an hypothesis.

The empirical evidence that led to this hypothesis is found in the order of learning in a number of experiments. The fact that the experiments performed so far have been based on 9- and 10-item lists unfortunately obscures to some extent the "true" order of learning the items, due to the fact that there are a large proportion of tied ranks in learning relatively short serial lists. That is to say, many *S*s, particularly fast learners, often attain the criterion on more than one item on a single trial, so that when the items are ranked in the order in which they are learned there are a good many tied ranks. The interesting point, however, is that while there are slight variations in the mean rank order of learning of the various positions in different experiments, the order with the closest fit to all experiments is that described in the Introduction. The hypothesized order correlates at least as high with the mean order of learning in various experiments as the rank order of learning in these experiments correlate with each other The overall agreement in order of learning among five different experiments totalling 200 *S*s, with different serial orders of the items and different pacing intervals, is indicated by an average rank order correlation (rho) of .92. The average rank order correlation between these experiments and the hypothesized order is .95.

The degree of agreement among individual *S*s in the order of learning was determined by means of Kendall's coefficient of concordance *W*, which was between .55 and .70 for various sets of data. Thus, there is a substantial degree of agreement among *S*s in the order in which they learn the items in a serial list. Certain positions are almost never learned before certain other positions have previously been learned. Table 1 shows the percentage of times that a given position ranked 1st, 2nd, 3rd, etc., in the order of learning among a group of 120 *S*s who learned a 9-item list to mastery. The tied ranks, which were tabulated separately, are shown in the lower half of the table.

TABLE 1
PERCENTAGE OF OCCURRENCE OF EACH RANK ORDER OF LEARNING AT EACH POSITION FOR 120 *Ss*

Rank order	Serial position 1	2	3	4	5	6	7	8	9
1	53.49	27.91	3.49	1.16	.00	.00	.00	.00	13.95
2	28.37	31.07	16.21	4.05	.00	.00	1.35	.00	18.91
3	4.00	24.00	34.66	5.33	.00	1.33	1.33	4.00	25.33
4	1.70	13.56	23.73	30.51	.00	5.08	.00	10.17	15.25
5	4.70	2.35	16.46	22.34	9.41	9.41	2.35	14.11	18.82
6	1.43	1.43	2.86	12.85	15.71	15.71	20.00	28.56	1.43
7	1.11	1.11	4.44	15.55	15.55	21.11	20.00	21.11	.00
8	1.59	.00	1.59	9.52	30.15	26.98	19.04	11.11	.00
9	.00	.00	1.28	2.56	34.61	17.95	35.90	7.69	.00
1.5	40.82	30.62	8.16	4.08	.00	.00	2.04	.00	14.29
2.5	19.57	28.26	10.87	6.52	.00	4.35	2.17	2.17	26.09
3.5	8.89	11.11	26.67	11.11	.00	4.44	4.44	4.44	28.89
4.5	2.50	5.00	20.00	22.50	5.00	7.50	2.50	10.00	25.00
5.5	.00	3.45	10.34	24.14	3.45	13.79	10.34	31.03	3.45
6.5	2.17	6.52	8.70	19.57	8.70	13.04	15.22	26.09	.00
7.5	.00	.00	3.13	9.37	15.63	28.13	25.00	18.75	.00
8.5	.00	.00	3.17	3.17	30.15	25.39	25.39	11.11	1.59

5. *Order of Learning Serial Lists of Verbal Materials*

How well does the hypothesized order correspond to the rank order of errors in serial-position curves reported in the literature, which are based on lists of nonsense syllables and other verbal materials? To find out, the investigator collected all the serial-position curves he could find in the experimental literature—70 in all. They were based on lists of from six to 18 items. The mean rank order of learning the items as inferred from the data points in the serial-position curves was determined for every length of list. The Pearson *r* was used as the measure of correlation between the actual order of learning found in the literature and the theoretical order. Table 2 presents the results. It should be noted that the correlations, representing the "fit" of the theory to the actual data, are approximately as high as the "reliability" of the rank order of the actual data. The coefficient of concordance, *W*, is a measure of the average agreement between the individual lists. It is generally over .90. A number of other possible rank orders were correlated with the actual data to see if any better fit could be obtained, but no other order has as consistently close a fit, when measured by Pearson *r*, as the order described in the theory section of the Introduction.

TABLE 2
CORRELATIONS (PEARSON *r*) BETWEEN RANK ORDER OF LEARNING ITEMS IN SERIAL LISTS REPORTED IN THE LITERATURE AND THE THEORETICAL ORDER OF LEARNING

Number of positions in serial-position curve	Number of curves	W*	*r*
6	2	.91	.97
8	9	.93	.98
9	7	.91	.96
10	21	.73	.97
11	1	—	.99
12	16	.85	.98
13	2	.95	.96
14	7	.92	.97
15	4	.98	.93
18	1	—	.86

* *W*, the coefficient of concordance, indicates the degree of agreement between the individual curves.

D. DISCUSSION

Supportive evidence for the proposed theory is found in a number of highly relevant experiments in the literature.

The one-trial, all-or-none conception of serial learning is given support in an experiment by Bolles (2), who changed the items in the middle positions of a serial list one-third of the way through learning and found that the number of trials to learn the middle positions did not differ significantly from the number required by a control group for whom there was no change in the serial list throughout the course of learning. Bolles concluded, "The results of this study support the view that the associative strength of S-R sequences in the middle of the list is not gradually built up in a continuous manner through all of the trials. It seems more likely that the learning of the middle syllables begins after the adjoining syllables have been learned" (2, p. 579).

Rather indirect evidence that the serial list is learned piecemeal is found in a study by Obrist (10), who measured the GSR during the course of learning a serial list and found that early in learning the GSR was greatest during the anticipations at the beginning and end of the list and that as the *S* approached the criterion of mastery the GSR became greatest during the anticipations in the middle of the list. From this it does not appear that the *S* was attending to or trying equally hard on every item in the list on every trial, or that he was having greater "difficulty" with the middle items in the series as a result of the development of inhibition or interference during the course of learning. The GSR followed the course of learning and "radiated" out from the first item or anchor point on successive trials.

The assumption concerning the effect of memory span on the skewness of the serial-position curve receives support from an experiment by the investigator to be reported in detail elsewhere. It was found that the serial-position curve of *S*s with a large memory span, as measured independently of the serial learning task, was more skewed or humped to the right than was the curve for *S*s with a small memory span. Also, *S*s who had been trained on a large number of serial learning tasks produced serial-position curves at the end of training that were more skewed than were the curves derived from their first attempts at serial learning.

The theory holds that memory span has less effect the longer the list. Support for this assumption is found in an experiment on memory span by Waugh (13), who showed that "When a series is relatively short . . . a relatively large number of consecutive items are recalled from either end of the series. When a series is relatively long . . . the terminal and initial spans are relatively short. The terminal span seems in this case to be independent of list length . . ." (13, p. 78). These are the very conditions stated by our theory to account for the greater skewness of short serial lists, i.e., lists of fewer than about eight items.

In comparing the serial-position curves of *S*s of superior intelligence (IQ 120-139) with the curves of subnormal *S*s (IQ 40-59), Barnett, Ellis, and Pryer (1) found no over-all difference in the degree of bowing of the serial curves, but did find a difference significant at the one per cent level in the percentage of errors at the second position in a 1-item list. The mentally retarded *S*s had a significantly greater proportion of errors on the second item in the list. The superior *S*s had a significantly greater proportion of errors at the fifth position. Since we know from the subtests of the Stanford-Binet and Wechsler intelligence tests that mentally retarded *S*s generally have a short memory span as compared with intellectually superior *S*s, these differences in the shape of the serial-position curve are exactly what the proposed theory would lead us to expect.

Similar differences in relative errors in the first two or three positions were shown by Malmo and Amsel (7) in comparing the serial-position curves of psychiatric patients having symptoms of severe anxiety with the curves of normal *S*s. Since there is evidence that anxiety adversely affects immediate memory span (11, p. 185; 12), the theory would predict a greater proportion of errors on the first two or three positions for the anxious as compared with the nonanxious *S*s. This is exactly what Malmo and Amsel found.

The theory also states that differences in the degree of flatness or peakedness of the serial-position curve are associated with the degree of agreement among *S*s in the order of learning the items. If the anchor point is somehow obscured or if peculiarities in the composition or presentation of the list increase the effects of idiosyncratic associations, fluctuations in attention, etc., there should be less unanimity among *S*s in their order of learning. Workman (14) obscured the "anchor" points in the list by omitting the first and last items after the first trial, which apparently had the effect of weakening the usual anchor point and of enhancing a more idiosyncratic choice of anchors. The serial-position curve that resulted was quite atypical and nondescriptly irregular. Glanzer and Peters (3) presumably varied the degree of accentuation of the anchor point by varying the duration of the intertrial interval from 0 to 3 to 12.5 seconds, with a presentation rate of 1.5 seconds per item. They found that "As spacing increases, the [serial-position] curve moves from a relatively flat, irregular curve toward the classic bow-shaped curve. The effect, as evaluated by the interaction of spacing with serial position, is significant at the .001 level" (3, p. 8). According to our theory the agreement among *S*s in order of learning should increase with increased spacing, which emphasizes the anchor point, and the increase in agreement among *S*s in order of learning would result in the increasingly bowed curve. Glanzer and Peters determined the degree of agreement in order of learning by means of Kendall's coefficient of concordance; for the three conditions of intertrial spacing (0, 3, and 12.5 seconds) the *W*s were .14, .43, and .47 respectively. Glanzer and Peters concluded that "These coefficients indicate that the individual curves within a group were becoming more alike as spacing increased" (3, p. 9).

E. SUMMARY

A theory was proposed to explain the bow-shaped serial-position curve. The theory is based on five assumptions for which some empirical support is offered: (*a*) the associative connections between the items are learned in a one-trial, all-or-none fashion; (*b*) connections are learned in a certain order around an "anchor" point, which is usually the first item presented; (*c*) the order is determined by the relative ease of forming an associative connection with an already learned item as compared with an item that is unfamiliar or not "anchored" as to serial position; (*d*) the "effort" required by a given *S* to learn the associative connections between items is equally divided among all items in the list; (*e*) the degree of skewness of the serial-position curve is a function of the interaction between the length of the series and the *S*'s immediate memory span.

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