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# Two Storage Mechanisms in Free Recall[1]

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Two experiments were carried out to test the hypothesis that the bimodal serial position curve in free recall is produced by output from two storage mechanisms—short-term and long-term. Experimental operations were applied that were predicted to have a distinct effect on each of these mechanisms, and the changes in the serial position curve were observed. In the first experiment, presentation rate and repetition of individual words were varied in order to affect long-term storage and thereby affect the beginning sections of the serial position curve. Presentation rate has the predicted effect of differentially raising the beginning section of the serial position curve. It does not affect the end section. Repetition, however, did not have any effect that could not be ascribed to presentation rate. It could not, therefore, be used to demonstrate independently the predicted differential effect. In the second experiment, delay between end of list and recall was varied in order to affect short-term storage and, thereby, the end section of the serial position curve. The predicted effect was clearly demonstrated. The results make it possible to systematize a number of findings in the literature.

In a free-recall task, *S* is presented with a series of words, which he then tries to recall. He is permitted to recall the words in any order that he wishes. The data obtained from this task characteristically show a pronounced serial position effect. The plot of the probability of recall as a function of the position of the word in presentation is U-shaped, with the beginning peak usually lower than the end peak.

The hypothesis proposed here is that the U-shaped serial position curve consists of two curves, each curve representing output from a separate storage mechanism. One is a long-term storage mechanism, the other is a short-term storage mechanism. It follows from the assumption of a long-term and short-term storage mechanism that the material recalled from the beginning of the list should be primarily output from long-term storage, that from the end of the list primarily output from short-term storage. From the initial decline in the serial position curve and the preceding statement, it may be further asserted that the capacity of long-term storage is limited. The more items that are already in, the less likely that there will be place for a new item. By definition, the short-term storage mechanism is limited not with respect to capacity but with respect to the amount of time it can hold an item.

The proposal then is to view the usual serial position curve as a composite of two output curves—one, declining from beginning to end of list, represents output from

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long-term storage. The other, rising from beginning to end of list, represents output from short-term storage. The amount of overlap between the two curves in a given set of data cannot be specified at present. It is, in part, the aim of this study to develop information on this point.

The distinction between long-term and short-term storage has been developed in the work of Hebb (1949) and Broadbent (1958). Experimental work on short-term storage has been carried out by a number of investigators, starting from the work of Broadbent (1958), Brown (1958), Conrad (1957), and Peterson and Peterson (1959). This work, including a study using a two-factor approach (Waugh, 1960) that has points of similarity with the one used here, has been concerned almost wholly with fixed-order recall.[2] Surveys of the developments in the area and the theoretical questions involved may be found in recent papers by Melton (1963) and Postman (1964).

In order to support the view proposed above, the attempt will be made here to separate the two hypothesized curves. This will be done by means of experimental operations which have a differential effect on the beginning and end sections of the serial position curve. As will be pointed out subsequently, some of these differential effects have already been demonstrated in the literature.

There are well-established procedures that are used to produce long-term storage. These are rote-learning procedures. The variables that affect the efficiency of rote learning—presentation rate, number of presentations, meaningfulness, etc.—suggest the operations that should have their effect on the beginning section of the serial position curve. Short-term storage should, by definition, be affected primarily by the amount of time which has elapsed since presentation. This variable, amount of time elapsed, should therefore have its effect on the end section of the serial position curve.

The aim of this study is, then, to test the hypothesis that there are two distinct storage mechanisms that produce the serial position curve in free recall. The strategy is to use variables which should have one effect on one storage mechanism and a different effect (either no effect or an opposed effect) on the other storage mechanism. These variables should give predictable changes in the shape of the serial position curve.

## Experiment I

The purpose of this experiment was to change the shape of the beginning of the serial position curve by affecting, primarily, the efficiency of long-term storage. The two main variables used were interval between successive items, or presentation rate, and repetition of items in the list. Since an increase in the interval between items usually facilitates rote learning, an increase should raise the beginning but not the end section of the serial position curve. By the same reasoning, repeated presentation of an item should have the same effect.

### *Method*

There were five main experimental treatments generated by two experimental variables—spacing, or the interval between successive words (S), and number of presentations of each word in the list (P): single spacing and presentation (1S/P)—each word presented once at a 3-sec rate; double spacing (2S)—each word presented once at a 6-sec rate; triple spacing (3S)—each word presented once at a 9-sec rate. There was a further subdivision of the 2S and 3S treatments noted below.

Parallel to the 2S and 3S conditions, were the 2P and 3P conditions: 2P—each word presented twice in succession, all at a 3-sec rate; 3P—each word presented three times in succession, all at a 3-sec rate. (A new word, however, appeared only every 6 or 9 sec.) Since the number of different words in each list was always the same, the total time taken to present a 2P and 2S list was the same. Similarly, the total time taken to present a 3P and

[2] The task used by Peterson and Peterson (1959) is viewed here as a fixed-order recall task, since *S* was required to recall the letters of the trigram in the order that they had been presented.

3S list was the same. The S conditions, depending on the location of the additional interitem intervals, were further subdivided into SA and SB conditions. If the 1S/P condition[3] is taken and an additional 3-sec interval is inserted after each word, a 2SA (after) condition is obtained. If the additional 3-sec interval is inserted before each word, a 2SB (before) condition is obtained. Similar placements of an additional 6-sec interval produce a 3SA and 3SB condition. The effect of these placements made a difference only at the beginning and end of the lists. In 2SA and 3SA an additional interval occurred between the last word of the list and the signal for recall; in 2SB and 3SB the additional interval occurred between the ready signal and the first word.

The main reason for using the two forms of the 2S and 3S conditions was to determine the source of possible differences between the 2S versus 2P, and 3S versus 3P conditions. If only one form of the S conditions had been used, differences between the S and corresponding P conditions might be interpreted as a result of differences in the interval between the first presentation of a repeated word and its recall, or differences in the interval between the last presentation of a repeated word and its recall. (If the 2S condition is viewed as identical with the 2P condition except for the elimination of one of the two presentations of each word, then elimination of the second member of each pair gives the 2SA condition, while elimination of the first member of each pair gives the 2SB condition. Similarly, elimination of the last two presentations of each repeated word in the 3P condition gives the 3SA condition, while elimination of the first two presentations of each repeated word gives the 3SB condition.) A secondary reason for using the two forms of the S condition was to obtain further information on the effect of delays without an interpolated task on recall.

### *Procedure*

All *S*s were presented with two 5-word practice lists and eight 20-word main lists consisting of common one-syllable nouns, drawn from the Thorndike-Lorge (1944) AA lists. The lists, recorded on tapes, were composed of the same words in the same order. They varied for the groups only in the presentation rate, number of repetitions of the individual words, or location of the interitem intervals.

The lists were presented in succession to the *S*s during the course of a single session. After each list the *S*s had 2 min during which they wrote the words that they recalled, in booklets. Each list was preceded by a ready signal, and followed by a bell that signalled the end of the list and start of the recall period. The *S*s were tested in groups of 20.

### *Subjects*

The *S*s were 240 Army enlisted men. There were 40 *S*s in each of the following conditions: 1S/P, 2SA, 3SA, 2P and 3P. There were 20 *S*s in 2SB and in 3SB.

### *Results*

In scoring the lists, a word was considered correct if it was (a) the same as a list word, (b) a homonym, or (c) a recognizable misspelling of either. Thus, if the word "night" was given, "knight" or "nite" would both be scored correct. Repetitions of a word were not counted. The mean number correct for the eight lists at each serial position was computed for each *S*. These twenty means for each *S* form the basic data used in the analyses discussed below.

The serial position curves for the alternate forms of the spaced lists (2SA and 2SB; 3SA and 3SB) were examined to determine whether the placing of the interval at the end of the list had any effect. No marked or systematic differences were apparent in the curves. Analysis of variance of the data for the four groups found no significant effect of the placement of the interval ($F < 1$) and no significant interaction of this variable with the serial position effect, $F\ (19,2204) = 1.19$, $p > .10$. The interpretation of these findings will be discussed subsequently. Since, however, the variable of interval placement had neither an overall effect nor an effect on the shape of the serial position curve, the subsequent analyses of the data combine groups 2SA and 2SB into one group, and groups 3SA and 3SB into another group. The experimental conditions are therefore reduced to five: 1S/P, 2S, 3S, 2P, and 3P.

[3] In the 1S/P condition, each list was preceded by a spoken ready signal 4 sec before the first word; it was followed by a bell signalling the start of the recall period, 3 sec after the last word. These intervals were increased, as indicated, in the SA and SB conditions. In the P conditions the intervals used in the 1S/P condition were used.

Examination of the serial position curves for these conditions (Fig. 1) shows a clear and systematic effect of spacing and a similar but less clear effect of repetition. The curve for the 1S/P condition appears in both the top and bottom half of the figure. As spacing increases, the probability of recall is raised in all but the last few positions of the curve. The end peak remains unaffected. As repetition increases, there is a similar effect in going from the 1S/P condition to the 2P condition, but no further systematic change in going from 2P to 3P. Comparison of the curves in the top half of Fig. 1 with those of the bottom half indicates that repetition has little or no effect beyond that of the spacing between new words.

The data were analyzed by analysis of

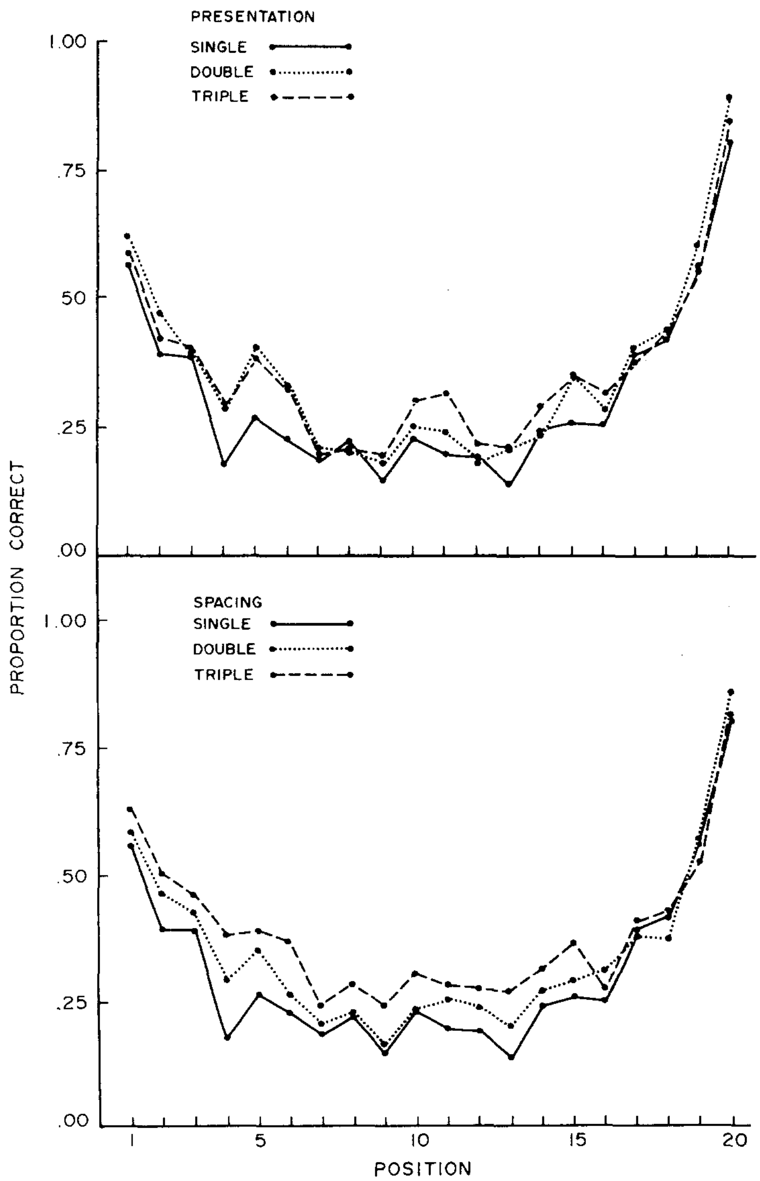


FIG. 1. Serial position curves for single (1S/P), double (2P), and triple (3P) presentation above; for single (1S/P), double (2S), and triple (3S) spacing, below. Each point represents the mean for eight lists and either 40 or 60 *S*s.

variance with the five main treatments (1S/P, 2S, 2P, 3S, 3P) as a between-subjects variable and serial position as a within-subjects variable. The four degrees of freedom associated with treatments were then broken down into three components: (a) The general effect of spacing the interval between new words, whether or not repetition occurred between the new words. This was evaluated by comparing 1S/P, 2S + 2P, and 3S + 3P ($df = 2$); (b) The effect of repetitions of the words in addition to the effect of spacing *per se*. This was evaluated by comparing 2S + 3S and 2P + 3P ($df = 1$); (c) The interaction of spacing and repetition ($df = 1$).

The overall effect of treatments is significant, $F(4,235) = 2.69, p < .05$. The effect of spacing is significant, $F(2,235) = 4.61$, $p < .025$, but neither the additional effect of repetition ($F < 1$) nor the interaction of spacing with repetition, $F(1,235) = 1.34$, $p > .10$, is significant. The within-subjects effect of serial position is highly significant, $F(19,4465) = 236.66$, $p < .001$. Reduction of the degrees of freedom to 1 and 235, giving a lower-bound, conservative test for a repeated measurements design (Greenhouse and Geisser, 1959), leaves this effect significant at the .001 level. The interaction of spacing with serial position is significant at the .005 level, $F(38,4465) = 1.79$, but is no longer significant under the conservative test, with degrees of freedom reduced to 2 and 235. The remaining interactions are negligible.

The conservative test of the interaction between spacing and serial position is actually doubly conservative, since it does not focus on the specific differences expected under the hypothesis of two storage mechanisms. To focus on the predicted effects, a separate test was made of the effect of the three spacing conditions (1S/P versus 2S + 2P versus 3S + 3P) on the sum of correct responses for successive groups of five serial positions. The degrees of freedom for each of these tests are 2/235. For the first five positions $F = 23.46$, $p < .001$; for the second five, $F = 16.21$, $p < .001$; for the third five $F = 22.00$, $p < .001$. For the last five positions, however, the effect of spacing is not significant—$F = 1.71$, $p > .10$.

It might be argued that absence of significant differences in the last section of the curves is due to a ceiling effect since the probability of recall of the last word is approximately .85. The probabilities of recall for words 15 through 19, however, run lower than the probabilities for positions 1 through 5, which do show significant differences. Comparing the sums for positions 15 through 19 gives an $F = 1.80$, $p > .10$. The ceiling effect cannot, therefore, account for the absence of differences at the end of the curve.

### *Discussion*

The results indicate that spacing, i.e., the rate at which new words are presented, affects the shape of the serial position curve. These results agree with findings of an experiment by Murdock (1962), in which 20-word lists were given at presentation rates of a word every 1 sec and a word every 2 sec. The curves obtained for the two conditions are very similar to those on the bottom of Fig. 1, with the spacing affecting all of the positions except the last few. The presence of a regular ordering of the spacing conditions up to and including the 15th position suggests that the items are still being recruited for long-term storage well towards the end of the list.

It had been expected that adding repetition of the words in the intervals between new words would increase the differences between the serial position curves. This was clearly not so. The repetition, indeed, seems to counteract the spacing effect.

The absence of a repetition effect is surprising for two reasons. First, a preliminary check of the accuracy with which *S*s could hear the words in the repeated and corresponding spaced lists indicated, as might be expected, that the *S*s heard the words in the repeated lists with slightly more accuracy. The check was carried out by presenting the lists to four groups of *S*s drawn from the same population as the experimental groups. Four groups, consisting of 14 to 15 *S*s each, listened to the 2S, 2P, 3S, and 3P lists and recorded each new word as they heard it. The interval between the successive words gave the *S*s ample time to record each new word. Comparison of the total number correctly recorded in each group indicated a tendency for more words to be recorded accurately by the groups that heard the lists with repeated words. The tendency, however, did not attain statistical significance, $F(1,55) = 3.80$, $.05 < p < .10$.

The absence of a repetition effect is also surprising because in the repeated conditions the *S*s had 2 or 3 presentations to learn each word. Viewing the successive repetitions as learning trials leads to the expectation that the probability of recall of a particular word be higher in the repetition condition than in the corresponding spacing condition. It is clear both from the statistical analysis and the curves in Fig. 1 that nothing like this occurred. The curve for the 3P condition actually lies slightly lower than the curve for the 3S condition.

There are several possible reasons for the absence of this effect. One is that simple repetition without active participation by the *S* may not be effective for learning the words in these lists. Another possible reason is that the particular form of repetition used here—immediately successive repetition—generates effects that counter the effects of learning.

There are two aspects of the data that give information on the effects of delay when no interpolated task is imposed. One is the absence of any effect of spacing on the end peak of the serial position curve. If simple amount of time between presentation and recall were effective, then it would be expected that all points in the end peak would be lowered as spacing increased from 1S/P to 2SA to 3SA. There was no evidence for such an effect. Similarly, it would be expected that all points in the end peak, except the last one, would be lowered as spacing increased from 1S/P to 2SB to 3SB. Again, there was no evidence for such an effect. This is interpreted here as indicating that passage of time without an interpolated task has no effect on short-term storage. The finding is in line with other findings in the literature on fixed-order recall (Brown, 1958).

Another aspect of the data that indicates that pure passage of time does not cause loss in short-term storage is the absence of differences between the 2SA and 2SB conditions, and also between the 3SA and 3SB conditions. In the 2SA and 3SA conditions, there were additional delay periods between end of list and recall. As was noted earlier, these additional delays had no effect. The relevance of these findings to the development of an effective delay procedure will be discussed further in Exp. II.

In summary, the results with the variable that was effective in the experiment—spacing or presentation rate—support the hypothesis. There is an effect on the beginning but not on the end section of the serial position. The results with a second variable, repetition, did not have any overall effect beyond that of spacing and therefore did not furnish any further information for the evaluation of the hypothesis.

## Experiment II

The purpose of the second experiment was to study the separate output of the hypothesized short-term storage mechanism. The strategy again was to introduce a variable that would have a different effect on long-term and short-term storage and thus have a different effect on the beginning and end peak of the serial position curve. The variable selected was delay between the end of the list and start of recall.

Before determining the form in which this delay would be imposed, the effects of pure delay, i.e., delay without an interpolated task, were investigated further. The weight of evidence from the fixed-order recall experiments indicates that pure delay has no effect on short-term storage. The subsidiary evidence in Exp. I on the effects of pure delay also indicated that it had no effect. The effects of pure delay were, however, examined further because the interpretation of predicted differential effect of delay would be simplest if no interpolated task were used. There was reason to believe that the free recall task differed sufficiently from the fixed-order recall tasks that had been used, to make it worthwhile to investigate the effects of pure delay on the free-recall task. Moreover, even for the fixed-order recall task there is at least one instance in which pure delay results in a drop in total amount recalled (Anderson, 1960).

A pilot study was, therefore, carried out in which two groups of *S*s were each given four 30-word lists, one group with no delay before recall, the other group with 30-sec delay. There was no interpolated task during the delay. A significant reduction of the end peak was found with 30-sec delay, $F(1,233) = 37.00$, $p < .001$. There was no marked effect of delay on the beginning peak, $F(1,233) = 2.67$, $p > .10$. The effect on the end peak was, however, small in magnitude, with the serial position curve showing a clear end peak after a 30-sec delay.

It was therefore decided to require the *S*s to carry out a minimal task during the delay periods used in this experiment. It was expected that, under these conditions, as the amount of delay increased, the height of the end peak would decrease but the beginning peak would remain unaffected.

## *Method*

*Subjects.* The *S*s were 46 Army enlisted men.

*Materials and Equipment.* The words were shown on a screen, with an automatic slide projector. The words were 240 AA monosyllabic nouns drawn from the Thorndike-Lorge list (1944). Each word was printed in black on a light blue background.

## *Procedure*

The *S* was first shown three 5-word practice lists, and then fifteen 15-word lists. Each word was shown for 1 sec with a 2-sec interval between successive words. The *E* read each word as it appeared. After the last word in each list, the symbol #, or a digit from 0 to 9 was shown. If the crosshatch symbol appeared, *E* said "write," and the *S* immediately started writing all the words he could recall in his test booklet. If a number appeared, the *S* started counting out loud from that number until *E* said "write." While the *S* was counting, *E* would measure either 10 or 30 sec with a stop watch before telling him to write. Each of the delay conditions was used with each of the three practice lists and with five of the main lists. The *S*s were individually tested. For each *S* the words were assigned at random to the lists and order of the delay conditions within the three practice lists and within the fifteen main lists was assigned at random. This meant that each *S* received a different set of lists and a different sequence of delay conditions.

After each list, the *S* was given a minimum of 1 min and a maximum of 5 min to complete his recall of each list. After the completion of each session *E* went over the booklet with the *S* to make sure that all the words were legible.

## *Results*

The results are summarized in Fig. 2. Each curve represents 5 lists recalled by the 46 *S*s. The 10-sec delay was sufficient to remove most of the end peak. With a 30-sec delay there is no trace at all of the end peak.[4]

Analysis of variance was carried with positions, and delay interval as within-subjects variables. Both variables and their interaction are significant at the .001 level or better—position $F(14,630) = 24.87$, delay interval, $F(2,90) = 19.75$, and their interaction, $F(28,1260) = 2.29$. Evaluation of the *F*s with reduced degrees of freedom, here 1 and 45, leaves the effect of position and delay interval both significant at the .001 level. The interaction, however, is not significant, under this conservative test. Since, however, the effect was specifically predicted for the end peak, a separate analysis was made of the effect of the delay condition on the sum of correct responses for successive sets of five positions in the curves. The degrees of freedom for these tests are 1/45. For the first five positions, $F = 3.60$, $p > .05$; for the second five positions $F = 1.44$, $p > .10$. The effect of delay is significant

[4] Since the submission of this paper, similar results have been reported by Postman, L. and Phillips, L. W., *Quart. J. exp. Psychol.* 1965, **17**, 132-138.

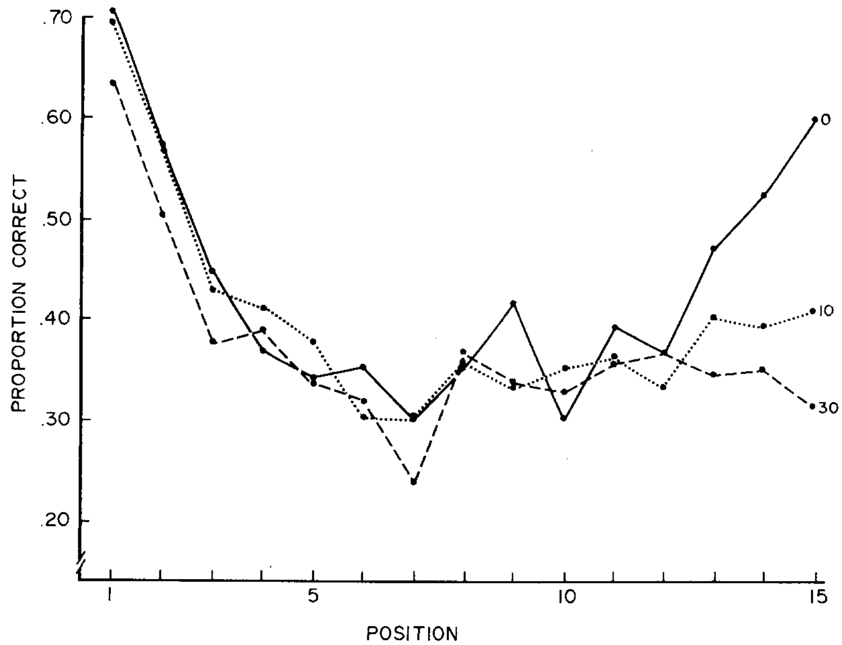


FIG. 2. Serial position curves for 0-, 10-, and 30-sec delay. Each point represents the mean for five lists and 46 *S*s.

only in the last five positions—$F = 22.42$, $p < .001$.

There is one characteristic of the no-delay curve that makes it differ from the usual serial position curve—the end peak is lower than the beginning peak. This may be due to the special characteristics of this experiment, in which *S* was exposed to delay conditions that lowered the efficiency of recall of items from the end of the list. This could have led to a strategy for handling the lists that emphasized the beginning items of the list.

### *Discussion*

The results of Exp. II give further support to the hypothesis of two distinct storage mechanisms. Again, it was demonstrated that an experimental operation had a predicted, differential effect on the peaks of the serial position curve.

The hypothesis furnishes a simple explanation for the serial position curve in free recall. It also furnishes a basis for further assertions about free recall which are supported by findings in the literature. Or, to say the same thing another way, the hypothesis makes it possible to systematize a number of findings in the literature:

(1) Word frequency, a variable that has an effect on rote learning, and, therefore, presumably on long-term storage, should have an effect on the beginning peak of the serial position curve. This assertion is supported by recent findings by Sumby (1963).

(2) Linguistic constraints in the words of the list, a variable that has an effect on rote learning, and therefore, presumably, on long-term storage should have an effect on the beginning peak of the curve. This assertion is supported by findings by Deese and Kaufman (1957).

(3) Requiring the *S* to recall the items in forward order should depress the end peak of the serial position curve. By requiring sequential recall, *E* imposes a delay with an interpolated task—recall of the early list items. This permits the loss of items from short-term storage. This assertion is supported by findings by Deese (1957) and Raffel (1936).

The approach used here is not presented

as a complete theory for free recall. A complete theory would permit derivation of the exact form of each of the hypothesized component curves. Once such a derivation is available then it would be possible to move away from the gross distinction between short-term and long-term storage. In a complete theory, the derivation of the output curve for long-term storage would, moreover, be based on specific assumptions about the processing involved in long-term storage. This would make it possible to move away from the simple identification of long-term storage variables with those affecting rote learning. The assumptions should also permit derivation of the characteristics of recall under more complex conditions than those considered here—for example, repeated presentations of the same word list.

The attempt to build a complete theory could, of course, be based on a variety of other constructs. For example, an approach could be developed by using inhibition or interference constructs—more specifically the constructs of proactive and retroactive inhibition. Using these constructs to build towards a complete theory leads to some complexities which will be briefly pointed out here.

The application of these constructs to account for the asymmetrical, bimodal shape of the usual serial position curve would require the specification of two functions, one relating amounts of PI to each position in the list, the other relating amounts of RI to each position in the list. If RI is considered simply as a function of the number of items following a given position, and PI simply as a function of the number of items preceding a given position, then the two functions might reasonably be expected to be monotonic. Two monotonic functions of this type and a simple rule for summing the inhibitory effects will not produce the standard type of U-shaped curve such as those in Fig. 1. By using values from Fig. 1, the difficulty may be summarized as follows. The probability of recall of the first list word is approximately .60. The probability of recall of the last list word is approximately .85. It may be assumed that there has been a reduction of .40 at the first position due to RI and a reduction of .15 at the last position due to PI. The probability of recall at the middle position is approximately .25. Within an inhibitory theory, this would be viewed as a reduction of .75 at those positions. The middle positions would be expected, if the RI and PI position functions are monotonic and if their effect is combined by addition, to have much higher probabilities of recall than those actually obtained. There are two ways of coping with this problem. One way is to move away from a simple additive system[5] allowing, for example, for interaction effects. The other way is to move away from simple functions. For example, PI for a position may be considered to be a function of both the number of items preceding the position, and the number of items following the position (time elapsing before recall).

Other complexities develop in applying inhibitory constructs to account for the systematic effects found in the experiments reported above. It is possible to use the PI construct to explain the effect of delay in Exp. II by assuming that PI is a function of both number of preceding items and the time that elapses during the delay interval. The statement of the relations involved might go as follows: Earlier items which have been extinguished recover during the delay interval and then interfere with the recall of items from the end of the list. This statement implies, however, that the effect of delay should merely alter the proportion of early and late items recalled. For every late item that is proactively blocked there should be an early item in its stead. At the very least it could be expected that there should

[5] More technically, the simple additive system referred to here would be called a linear system, in which $f(RI) + f(PI) = f(RI + PI)$.

be some increase in the probability of recall of the early items. There is no evidence at all of such an increase. The only change that occurs is that the number of items from the end of the list decreases. Again, additions or alterations can be made to handle the obtained results. Again, however, the theoretical structure grows rather complex.

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