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THE SERIAL POSITION EFFECT OF FREE RECALL[1]

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Recently Murdock (1960) has shown that in free recall R_1, the total number of words recalled after one presentation, is a linear function of t, total presentation time. Nothing was said about the serial position effect, though this is a well-known phenomenon of free recall (e.g., Deese & Kaufman, 1957). However, given that there is a serial position effect, the simple linear relationship between R_1 and t is rather surprising.

In the customary serial position curve of free recall, probability of recall is plotted as a function of serial position. This means, then, that the area under the serial position curve is equal to R_1, the number of words recalled after one presentation. If R_1 is a linear function of t then it must follow that the area under the serial position curve is also a linear function of t. However, it is not immediately apparent how the serial position curve varies with t in such a way as to maintain this simple linear relationship.

The present experiment was designed as an attempt to determine how the serial position curve varied with list length and presentation rate while still maintaining this linear relationship. Unfortunately, at the end of the experiment it was still not clear how this relationship came about or, for that matter, whether the relationship was even linear after all. The basic reason for this failure was that the trends which did show up were not consistent enough to justify any clear-cut conclusions. However, a rather definite picture of the serial position curve itself did emerge from the data. Therefore, the present article will be restricted to a quantitive description and attempted explanation of the serial position curve of free recall.

PROCEDURE

Six groups each had a different combination of list length and presentation rate. These six combinations were 10-2, 20-1, 15-2, 30-1, 20-2, and 40-1; the first number indicates list length and the second number indicates presentation time (in sec.) per item. Thus, 10-2 means a list of 10 words presented at a rate of 2 sec/item. Notice that the first two, middle two, and last two groups were matched for t, total presentation time (20, 30, and 40 sec., respectively).

For each group there were 80 different lists. The lists were constructed by randomly selecting words from the (approximately) 4000 most common English words (Thorndike-Lorge, 1944, G count of 20 and up), except that homonyms, contractions, and archaic words were excluded.

Group testing was used. Lists were read to 5s either at every beat (presentation rate of 1 sec/item) or at every other beat (presentation rate of 2 sec/item) of an electric metronome set at a rate of 60 beats/min.

After each list there was a recall period of 1.5 min. The 5s wrote down as many words, as they could remember in any order that they wished. Each recall period was terminated by a verbal "Ready" signal which preceded the start of the next list by 5-10 sec. All groups were given 20 lists per session and four sessions; successive sessions were spaced 2–7 days apart. Nothing was said about rehearsing while the lists were being presented.

In all there were 103 5s, students of both sexes from the introductory psychology course who were fulfilling a course requirement. Exact *N*s by group are shown in Table 1.

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RESULTS

The data were first analyzed to determine if practice effects occurred over the four sessions. Analyses of variance showed that there was a significant ($P < .01$) improvement over the four sessions for Groups 10-2, 15-2, and 20-2; whereas the effect was significant at only the .05 level for Group 30-1 and was not significant ($P > .05$) for Groups 20-1 and 40-1. However, the largest difference obtained between the best and the worst session for any one group was 1.13 words, and all other intersession differences were less than 1.0 words. Therefore, when this practice effect is divided into four sessions and anywhere from 10 to 40 serial positions its effect on the serial position curves was negligible.

Table 1 shows the means and *SDs* of the number of words recalled per list (R_1). Each mean is based on 80 lists per *S* and from 15 to 19 & per group. As predicted, groups with the same total presentation time did not differ significantly in mean number of words recalled. That is, no significant differences were found between Groups 10-2 and 20-1 ($t = 1.39$), between Groups 15-2 and 30-1 ($t = 1.00$), or Groups 20-2 and 40-1 ($t = 0.48$).

TABLE 1

MEAN NUMBER OF WORDS RECALLED

Group	*N*	Mean	*SD*
10-2	18	6.39	0.76
20-1	16	6.87	1.16
15-2	19	8.25	1.40
30-1	19	8.82	1.98
20-2	15	8.53	2.08
40-1	16	8.24	1.08

The serial position curves are shown in Fig. 1. Probability of recall is plotted as a function of serial position. For greater generality, we would also like to use the data from studies by Murdock and Babick (1961) and Deese and Kaufman (1957). In the Murdock-Babick study there were 18 5s each tested on 80 different 25-1 lists. In the Deese-Kaufman study there were two groups of 16 *S*s each; one group was tested on 10 different 10-1 lists and the other group was tested on 10 different 32-1 lists. The

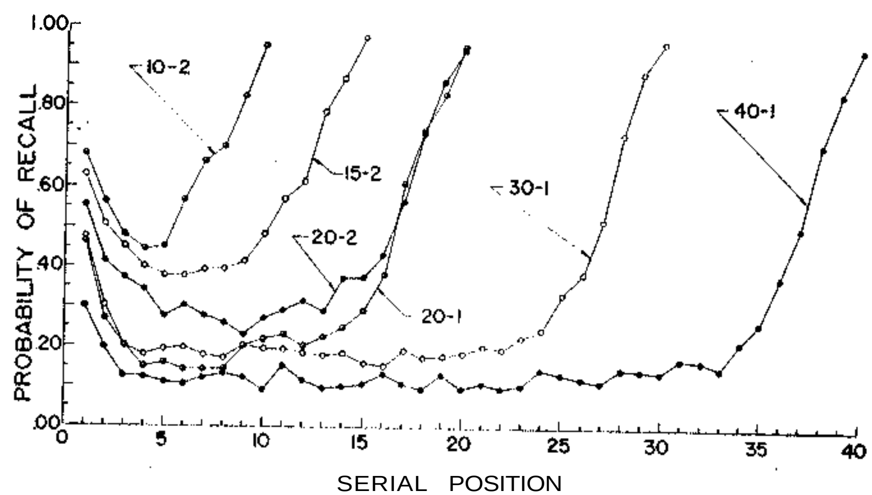

FIG. 1. Serial position curves for the six groups.

serial position data were presented in the original article as Fig. 1 (p. 182) and we read the points from the two curves as accurately as possible. These three serial position curves are shown here as Fig. 2.

We have, then, nine different serial position curves. In general, the curves seem to share certain general characteristics: a marked recency effect, a flat middle section, and a primary effect which is more precipitous though smaller in magnitude than the recency effect. The presence of a flat middle section, or asymptote, is clearest in the 40-1 list (Fig. 1), but becomes less and less obvious as list length decreases. Actually, in the two 10-word lists the primacy and recency curves may have intersected each other before an asymptote has been reached.

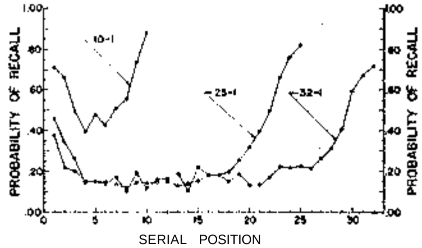

FIG. 2. Serial position curves for 10-1 and 32-1 lists (Deese & Kaufman, 1957) and 25-1 lists (Murdock & Babick, 1961).

More specifically, the recency effect can adequately be described by the Gompertz double-exponential function. As given by Lewis (1960, p. 81) the equation is $y = vg^{h^x}$. Probability of nonrecall (y) was plotted as a function of list length minus serial position (x). Thus, the last word in a list would have an x value of 0, the next to last word an x value of 1, etc. Both v and g were fractional and positive. The asymptote v was determined from the mean recall probabilities averaged over the flat part on each serial position curve. The constants g and h were obtained by a least squares method described by Lewis (1960, pp. 82-88) using the last eight points of each serial position curve (except of the two 10-word lists where only the last four or five points could be used).

The evidence for this conclusion is shown in Table 2 under the r^2 column. In all cases the Gompertz equation accounted for more than. 95% of the variance, and the mean coefficient of determination (r^2) was 97.79%.

Since in all nine cases $g < 1/e$ the recency effect is consistently an S shaped curve. This characteristic can be seen in the serial position curves of Fig. 1 and 2. Starting from the last serial position, each curve is initially positively decelerated and then soon becomes negatively decelerated.

TABLE 2

VALUES FOR GOMPERTZ DOUBLE-EXPONENTIAL FUNCTION TO FIT SERIAL POSITION CURVES IN FREE RECALL

Group	v	g	y_0	h	r^2	x_i	$x_{.95}$
10-2	.548	.100	.055	.574	97.3%	1.5	6.9
20-1	.852	.050	.043	.596	98.8%	2.1	7.9
15-2	.622	.026	.016	.518	97.8%	2.0	6.5
30-1	.814	.032	.026	.546	99.3%	2.0	7.0
20-2	.730	.048	.035	.552	95.9%	1.9	6.9
40-1	.88.5	.036	.032	.557	98.7%	2.0	7.1
25-1[a]	.851	.134	.114	.634	98.3%	1.5	8.1
10-1[b]	.566	.206	.117	.431	98.3%	0.5	4.1
32-1[b]	.840	.270	.227	.644	95.7%	0.6	7.4

[a] From Murdock and Babick (1961).
[b] From Deese and Kaufman (1957).

The y_0 column gives the value of y when $x = 0$. If y_0 is subtracted from 1.00 this gives the probability that the word in the last serial position will be correctly recalled. The results for the six groups of the present experiment were very similar to each other, and an analysis of variance of the number correctly recalled showed that the groups did not differ significantly ($F = 1.61$, $df = 5/97$, $P > .05$). The recall probabilities were rather high but they were not 1.00 (and had they been the Gompertz would not be applicable); the corresponding recall probabilities for the Murdock-Babick and Deese-Kaufman data were clearly lower.

The inflection point occurs between the second and third words from the end of the list and appears to be essentially independent of list length and presentation rate. The evidence for this conclusion is given under the x_i column of Table 2, where $x_i = -\ln(-\ln g)/\ln h$ (ln is log base e). That is, x_i is the inflection point, that x value at which the deceleration changes from positive to negative. The x_i values range from 0.5 words to 2.1 words with a mean of 1.57 words. Since the last word in any list has an x value of 0, a mean of 1.57 words places the inflection point midway between the second and third words from the end of the list.

Actually, both Deese-Kaufman curves appear to have inflection points nearer the end of the list than any of the other curves. Otherwise, however, the inflection points cluster rather closely in the range of 1.5–2.1 words.

The recency effect extends over the last eight serial positions and appears to be essentially independent of list length and presentation rate. The evidence for this conclusion is given under the $x_{.95}$ column, where $x_{.95}$ is that value of x at which the curve is 95% down. That is, at this point forgetting is 95%, of the asymptotic value. The 95% level serves as a convenient criterion to mark the end of the recency effect.

The mean of the $x_{.95}$ column is 6.88 words or, rounded off to the nearest whole number, 7 words. Except for the Deese-Kaufman 10-1 list all the values seem to be very close to 7 words. Since the x value is 7 words, the recency effect extends over the last eight serial positions.

Another way of indicating the similarity among different lists is by the h column of Table 2. In the Gompertz the constant h determines the rate of change. Since the values of h are all rather similar this indicates that all curves have a similar rate of change, and if they have a similar rate of change all curves should level out at about: the same x value if the numerical values of g do not differ too greatly.

The primacy effect appears to extend over the first three or four serial positions. This can be seen in the serial position curves of Fig. 1 and 2, as all of the curves seem to level out at about the third or fourth serial position. The primacy effect is so short-lived that the curve is difficult to describe mathematically. Actually, it may well be exponential. Semilog plots of the first three or four points of the nine curves (using 1.00 — v as the asymptote for each curve) gave reasonable approximations to straight lines and the slopes were rather similar to one another. A group curve based on the mean ($y-c$) values of the individual curves was an excellent fit; the rate constant was 0.77 and the intercept was .27 (see Murdock & Cook, 1960). However, the fact that this group curve was based on only three points should make one hesitant about placing too much confidence in it.

Finally, the primacy and recency effects are spanned by a horizontal asymptote. The asymptote is considered to extend from Serial Position 5 up to the last eight serial positions. That is, in a 20-word list the asymptote would extend from Serial Position 5 through Serial Position 12, in a 30-word list from Serial Position 5 through Serial Position 22, etc. That the asymptote is essentially horizontal is suggested by the middle parts of the serial position curves of Fig. 1 and 2.

A close examination of the serial position curves suggests that the trend line may have a small positive

TABLE 3

PREDICTED AND OBTAINED INCREMENTS FOR ASYMPTOTE

Group	ΔX	Pred.	Obt.	Diff.
20-1	8	.039	.100	.061
30-1	18	.022	-.004	-.026
20-2	8	.019	.015	-.004
40-1	28	.027	.038	.011
25-1	13	.044	.036	-.008
32-1	20	.032	.046	.014

slope rather than a zero slope. However, this positive slope could be due to the fact that the recency effect is only 95% down; i.e., 5% of the effect remains to exert an effect on the (allegedly) horizontal asymptote. The proper test of this conclusion, then, is to determine whether the obtained increment (if any) is greater than the increment attributable to the 5% remaining from the recency effect.

The following analysis deals only with lists of 20 words or more; the 10 and 15 word lists could not be used because there were too few points. For each of the six lists the obtained increment was found by fitting a least squares regression line to the asymptote, determining its slope, then multiplying the slope by Δx where Δx is the difference between Serial Position 5 and the seventh-from-last serial position ($\Delta x = 8$ for the 20-word list, $\Delta x = 13$ for the 25-word list, etc.). The expected increment was found by obtaining the predicted y value from the Gompertz equation for the two values of x (Serial Position 5 and seventh-from-last serial position), then subtracting. For each list the constants shown in Table 2 were used. The predicted and obtained increments are shown in Table 3; the difference between the predicted and obtained increments was not statistically significant ($t = 0.72$, $df = 5$). Thus, the asymptote does appear to be horizontal, and the slight positive slope to the curve is no greater than would be expected from the tail end of the recency effect.

DISCUSSION

We have presented data to show that the serial position curve of free recall is characterized by a rather steep (possibly exponential) primacy effect, an S shaped recency effect, and a horizontal asymptote extending between the primacy and recency effect. An idealized curve for a 24-word list is shown in Fig. 3. Its equation is

$$1.00 - .27e^{-.77(x-1)} - .772\,(.042)^{.556(L-x)}$$

where L is list length and x is Serial Position 1, 2, 3, . . . L. The constants for the primacy effect were those of the group curve discussed above while the constants for the asymptote and the recency effect were the mean values of the constants given in Table 2 for the six lists of the present experiment.

The curve of Fig. 3 is an empirical curve, not a rational curve. It is an attempt to describe the serial position effect of free recall quantitatively, not explain it. Not only does this empirical curve represent the nine curves of Fig. 1 and 2 quite well, but also it is consistent with several other sets of data. For one, it agrees with serial position curves for 20-1 lists reported by Deese (1957,

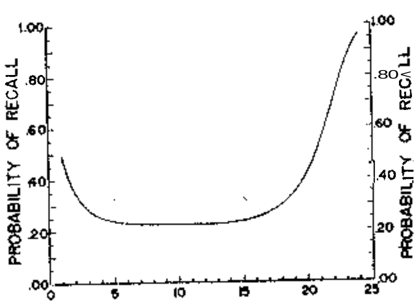

FIG. 3. Idealized serial position curve for 24-word list.

Fig. 1, p. 580). For another, it agrees well with some unpublished curves culled from several experiments recently reported by Murdock (1960). Finally, the exact same trends are present in some memory-span data reported by Waugh (1960, Fig. 3, p. 75).

However, the empirical curve of Fig. 3 is not in agreement with results reported by Bousfield, Whitmarsh, and Esterson (1958). These authors used 5-, 10-, 20-, and 40-word lists all presented at a rate of 2.5 sec/word, and consistently found the primacy effect more marked than the recency effect. Both Bousfield et al. (1958, pp. 260–261) and Deese (1957, pp. 581-582) suggest that the relatively slow presentation rate may have encouraged rehearsal and thus led to the greater primacy effect. To investigate this possibility, we conducted an additional experiment with 35 Ss using 10 20-2.5 lists. The 20-word length was selected because the curves of Bousfield et al. (1958, Fig. 1, p. 258) seemed to show the most pronounced primacy effect for this length list. As Bousfield et al. (1958) apparently used a somewhat longer recall period we used a 4-min. recall period in this additional experiment; otherwise the procedure was identical with that of the other experiments reported here.

The results of the experiment are shown in Fig. 4. As can be seen, in general the results are quite consistent with the empirical curve of Fig. 1, and in

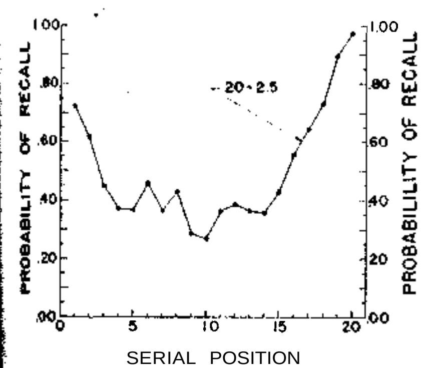

FIG. 4. Serial position curve for 20-2.5 lists.

particular the recency effect is more pronounced than the primacy effect. This experiment clearly shows that the results of Bousfield et al. (1958) are not due to the slower presentation rate per se.

Why did Bousfield et al. (1958) find primacy more pronounced than recency? One possibility is their instructions. Twice in their instructions they told Ss that the words were to be recalled, ". . . in the order in which they occur in your memory." The stress on order may have given Ss a set to recall the words in the order presented, and Deese (1957) has shown that instructions to Ss are an important variable in determining the shape of the curve. A second possibility is the design used. Bousfield et al. (1958) used a counterbalanced design such that each S had only one list at each length. Thus, in effect each list was (to S) of unknown length, and this fact may have encouraged rehearsal in the order of presentation.

In any event, under the conditions of the present experiment there seems little doubt that the serial position effect of free recall is essentially as depicted in Fig. 3. Of course, as Deese (1957, p. 581) has noted, the serial position curve is sensitive to the introduction of experimental variables. However, it has been found that more items are recalled with free recall than with ordered recall (Deese, 1957; Waugh, 1961), so evidently free recall is the preferred, perhaps even the more basic, method of recalling a list of unrelated words.

Finally, why does the serial position curve of free recall take the shape it does? One possible explanation is in terms of short-term proactive and retroactive inhibition. That is, each word in a list is both preceded by anywhere from 0 to (L — 1) other words and followed by anywhere from (L — 1) to 0 other words. Up to a point, the more preceding words the more short-term PI and the more succeeding words the more short-term RI. The PI and RI effects presumably summate to determine the total inhibitory effects.

If this explanation is correct, recent

studies of the short-term retention of individual items should provide an indication of the course of PI and RI to be expected. It has been found that, in short-term memory, PI effects appear to be greatest after about three prior words (Murdock, 1961). This agrees well with the finding that the primacy effect levels out after the first three or four serial positions. In short-term memory RI effects appear to approach an asymptotic value greater than zero (Murdock, 1961; Peterson & Peterson, 1959). This agrees well with the finding of a horizontal asymptote in the serial position curve. Finally, an examination of the RI curve of short-term memory even suggests an S shaped curve (see proportion of correct recalls over different retention intervals, Tables 1 and 3, Murdock, 1961, pp. 619-620). This agrees well with the Gompertz recency effect suggested here. Thus, it would appear that all the main characteristics of the idealized serial position curve shown in Fig. 3 are compatible with the results obtained from the short-term retention of individual items, and these findings lend support to the idea that the serial position curve of free recall is essentially a manifestation of short-term PI and RI effects.

SUMMARY

This experiment was a study of the serial position effect of free recall. Curves were obtained for 10-2, 20-1, 15-2, 30-1, 20-2, and 40-1 lists, where the first number indicates list length and the second number indicates presentation time per word. On the basis of the available evidence it was concluded that, under the conditions of the present experiment, the serial position curve is characterized by a steep, possible exponential, primacy effect extending over the first three or four words in the list, an S shaped recency effect extending over the last eight words in the list, and a horizontal asymptote spanning the primacy and recency effect. Finally, it was suggested that the shape of the curve may well result from proactive and retroactive inhibition effects occurring within the list itself.

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THE SCALING OF SUBJECTIVE ROUGHNESS AND SMOOTHNESS [1]

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These experiments begun us an attempt to apply the method of magnitude estimation to a continuum for which the stimulus seemed to have no metric scale, only an ordinal scale of grades of sandpaper, or emery cloth. Unexpected discoveries led on to more engaging inquiries. At the outset, both a ratio scale and a category scale of apparent tactual roughness were determined with 12 grades (grits) of emery cloth. The relation between the ratio scale and the category scale was typical of the relation found on prothetic continua. (For these first results, see Stevens, 1961a; for an earlier related study, see Dudek & Baker, 1956.)

The next study was an exercise in which two students, C. S. Harris and J. P. McMahon, asked 12 *Os* to judge the smoothness of the stimuli instead of the roughness. The ratio scale of smoothness approximated the inverse, or reciprocal, of the ratio scale found for roughness, and the category scale of smoothness was the reverse, or the complement, of the category scale of roughness. These results resemble Torgerson's (1960) findings when he scaled both the apparent lightness and the apparent darkness of gray papers.

In terms of a linear scale of apparent roughness, it turned out that the stimuli used were bunched rather tightly at the low (smooth) end of the continuum, so much so that the two category scales were almost logarithmic functions of the respective ratio scales. Other studies of category scaling suggest that the nearly logarithmic form found here is an accident of the stimulus spacing, and that if an iterative procedure were used to arrive at a "pure" category scale the curve for roughness would be less curved than a logarithmic function (Stevens & Galanter, 1957).

Since the available number of emery cloth grits is limited, it is difficult to determine a pure category scale, but when a sample of grits more uniformly spaced in subjective roughness was used, the form of the category scale changed as predicted: it became much less curved than a logarithmic function when plotted against the ratio scale of subjective roughness. Ten *Os* judged grits 320, 120, 80, 50, 40, 30, and 24 twice each on a seven-point scale. The average judgments were 1.17, 2.17, 3.04, 4.12, 5.17, 6.08, and 6.62. These values determine a line that is straighter than a logarithmic function—a line that is not far from the pure form of the category scale, as evidenced by the tendency of *Os* to use each category number approximately equally often (Stevens & Galanter, 1957). It appears, therefore, that: roughness behaves like a prothetic continuum, and that the pure category scale is not a logarithmic function of the magnitude scale (Eisler, 1962).

From these preliminary studies a surprising fact emerged: magnitude estimations of roughness, and of smoothness, turned out to give fairly straight lines when plotted in log-log coordinates against the grit number of the emery cloths. Another instance, it seems, of the psychophysical power law. (Grit number refers to the number of openings per inch in the screen employed to sift the abrasive particles.) If apparent roughness and its reciprocal, apparent smoothness, are power functions of particle size, it becomes a challenging task to determine more accurately the exponents involved. In the preliminary experiments, each involving 12 *Os*, the approximate exponents were — 1.5 for roughness and +1.2 for smoothness when measured against grit number. The next problem was to determine

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