Serial Position Curves in Verbal Learning

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When a list of nonsense syllables is learned by a subject under conditions that require him to recall the following syllable as each one of the series is presented, it is found that the syllables in the middle of the list are learned more slowly than are those at the two ends, and that in general the initial syllables are learned more rapidly than are the final ones. When the results are plotted in terms of mean number of errors made at each serial position during learning, the graph has the form shown in Fig. 1.

Of the various theories proposed in explanation of the relatively slow rate at which the middle of the series is learned, that of Lepley (*1*) and Hull (*2*) has been the most ingenious and perhaps the best substantiated. The Lepley-Hull theory is that the bow-shaped serial position curve results from the large number of inhibitory processes present in the middle of a series of responses. It is known that during learning each syllable becomes associated not only with adjacent but also with remote syllables, so that both near and remote excitatory tendencies are set up. Progress toward mastery of the list involves a strengthening of the near excitatory tendencies and the weakening (or control) of the remote ones to the point where, when a given syllable is presented, the subject will report the next following syllable and not one farther along in the list, or none at all. A simple diagram can be constructed to show that remote excitatory tendencies pile up in the middle of the list. Proceeding from this point, an analogy is drawn between serial learning and conditioning. It is held that each succeeding syllable in the series becomes conditioned to the traces of preceding syllables so that remote associations are viewed essentially as trace-conditioned responses. Final mastery is attained as a result both of the building up of internal inhibitions of the trace responses and of the strengthening of near excitatory tendencies. Inasmuch as the trace response tendencies are most numerous in the middle of the series, the inhibitory tendencies must be concentrated in the same location, to the relative neglect of the two ends. Many observations, particularly on the spontaneous recovery of extinguished responses, support the view that inhibitory tendencies dissipate more rapidly with the lapse of time than do excitatory tendencies. One can therefore make experimental tests of the effects of various manipulations of the time variable upon the serial position curve, looking for results that may or may not support the inhibition theory.

The most significant data on the serial position curve with respect to this theory come from experiments on massed vs. distributed practice and on changes in the rate of presentation of the syllables. In massed learning, practice periods follow one another with little or no rest between the periods, whereas in distributed learning there are rest periods of varying lengths at the close of each practice period. Within limits, distributed practice results in quicker learning than does massed practice. The inhibition theory predicts that the lapse of time involved in the rest periods of distributed practice will result in a relative loss of inhibitory tendencies and that, therefore, the serial position curve for distributed learning when compared with the massed learning curve will show a decrease in errors at each position but with the largest decrease in the middle portions of the curve, where the inhibitory effects have been greatest. Similar predictions are made for the effects of varying the rate at which syllables are presented, since, with a slow rate, inhibitory tendencies may be expected to dissipate more rapidly than with a faster rate of presentation.

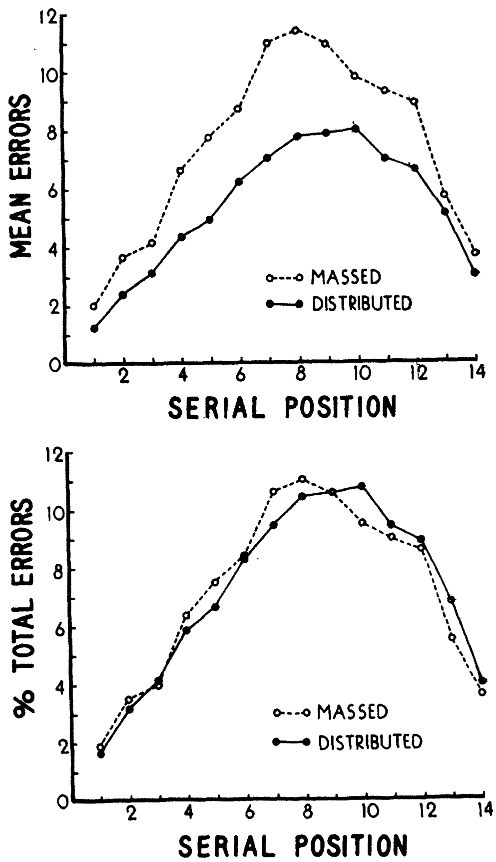

Fig. 1.

Patten (*3*) and Hovland (*4, 5*) have conducted experiments of the above type. The upper half of Fig. 1 shows the essential results secured by Hovland (one of many experiments) when subjects learned a list of 14 syllables presented at a rate of 1 syllable each 2 sec. In the distributed practice series, there was a rest interval of 2 min 6 sec between successive presentations of the list, whereas in the massed practice series the rest period was only 6 sec. The decrease

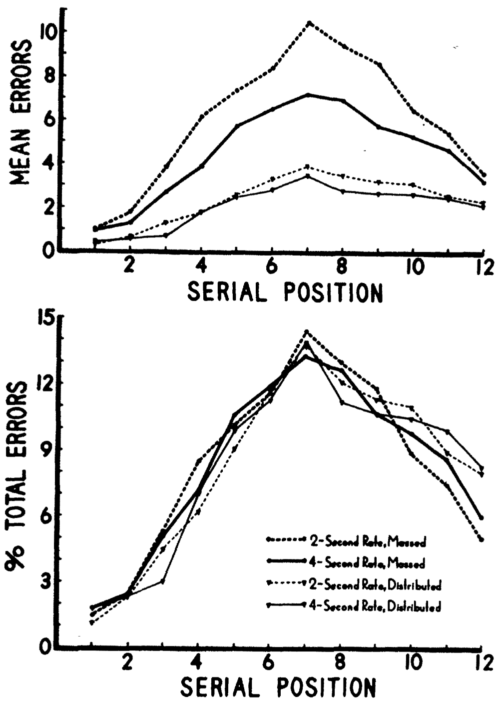

FIG. 2.

in mean errors brought about by distributed practice shows up at all serial positions, but it is greatest in the middle of the series, as predicted by the inhibition theory. In another experiment, Hovland compared the serial position curves for the learning of 12-syllable lists under conditions of massed vs. distributed practice, using 2-sec and 4-sec rates of presentation per syllable. The mean number of errors per serial position under these various conditions is shown in the upper half of Fig. 2. Again there is evident a marked decrease in mean errors when distributed practice is compared with massed practice, with the greatest decrease in the central portion of the curve. The change from a 2-sec to a 4-sec rate of presentation has little effect under conditions of distributed practice, but a significant effect in massed practice.

The curves in the lower halves of Figs. 1 and 2 show the serial position curves of the upper halves of the figures plotted in percentages, with the mean errors at each position expressed as a percentage of the total mean errors made under a given practice condition. (Since we did not have access to Hovland's original data, the values are computed either from his curves or from his tables. In either case any errors in the calculations would be small.) The striking feature of the percentage plots is that there is essentially no difference in the curves for the different conditions of learning. This is also true for the percentage plots we have made of the data in eight other investigations by various authors. In all cases there was practically complete identity of the percentage serial position curves for the greater and lesser conditions of efficiency within a given experiment, with a rare maximum difference of 3.5% for a given serial position.

The reason for plotting percentage mean error curves is as follows, stated in terms of the experiment on massed vs. distributed practice: Since distributed practice is more efficient than massed practice, fewer errors are made during learning under the former than under the latter condition. Graphs of mean errors per syllable position, therefore, must give two curves which differ in their ordinate values much as is the case in Fig. 1, irrespective of the explanatory theory being investigated. When the absolute mean error curves are equated for area by plotting them in percentage terms, any essential differences in form are observable. The percentage curves of Figs. 1 and 2 show that the several serial positions have the same order of relative difficulty under the more and the less efficient methods of learning. From the standpoint of the Lepley-Hull inhibition theory, the percentage curves are more significant than the mean error curves, since they show that the reduction of errors brought about by the introduction of elapsed time intervals occurs throughout the series in proportion to the total errors made and in the same overall manner as where no elapsed time is introduced. This does not prove the inhibition theory, but it is consistent with it.

In a further attempt to throw light on the serial position curve and on the relevancy of the inhibition theory, we have conducted an experiment on the serial learning of 14 nonsense syllables vs. 14 familiar names (an initial cue item was added to each list) by the conventional anticipation method counterbalancing the two series. In order to balance out any unevenness in difficulty of the specific items, each subject entered the list at a different point so that, for example, the syllable or name in serial positions 3 and 4 for one subject would be in positions 4 and 5 for another subject. The items were presented at a 2-sec rate, with the intertrial interval set at 8 sec. Learning was completed in one session, massed practice, to a

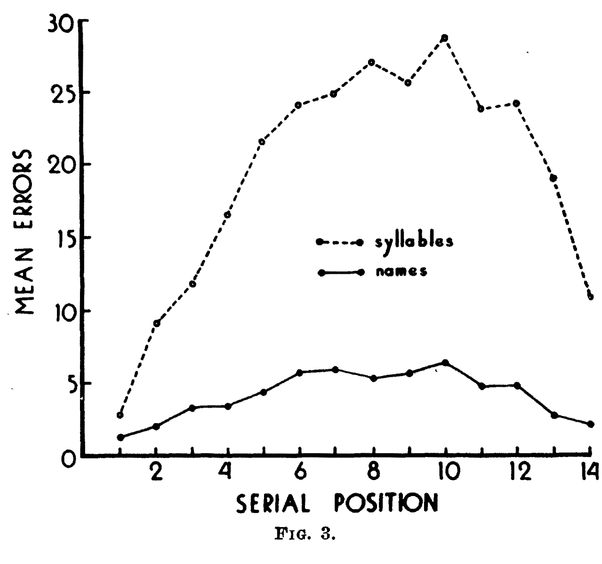

FIG. 3.

criterion of one correct anticipation of each syllable in the course of one trial. The association values of the syllables were from 0 to 3% according to Hull's calibration (*6*). The names were the family names of the 16 graduate students who served as subjects and who, at this time, were well acquainted with each other. The mean number of trials required for learning the syllables was 39 and for learning the names, 11.

Fig. 3 gives the serial position curves for syllables and names plotted in terms of mean errors, and Fig. 4 replots the same data in terms of the percentage of total errors made at each serial position. Again it is to be noted that (1) the curves are the familiar bow-shaped ones current in the literature, (2) the greatest gain in efficiency occurs in the middle of the series or just past the middle, and (3) the percentage plots are essentially identical. Items 2 and 3 above were brought about by the use of familiar names vs. nonsense materials as the material to be learned and not by the introduction of elapsed time, which might allow for a decrease of inhibitory tendencies as predicted by the Lepley-Hull theory.

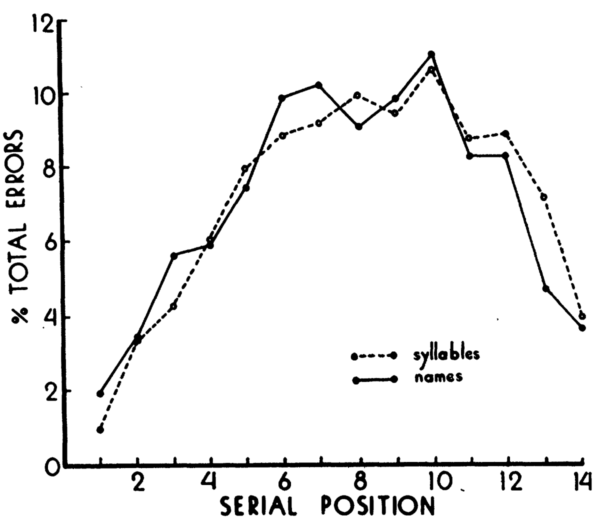

FIG. 4.

The 16 subjects of the above experiment were classified as quick or slow learners on the basis of being in the upper or lower half of the group in total errors made during learning. The upper half of Fig. 5 presents the serial position curves for these two groups in learning familiar names as described above, and the lower half gives the curves on a percentage basis. Similar curves were found for quick vs. slow learners in the nonsense syllable learning of these 16 subjects, as well as in the experiment (not here reported) with 48 subjects in the learning of familiar and unfamiliar nonsense syllables.

The general conclusions from the above experiments and analyses are as follows: (1) Any experimental condition which increases the efficiency of serial verbal learning and which thereby decreases the total number

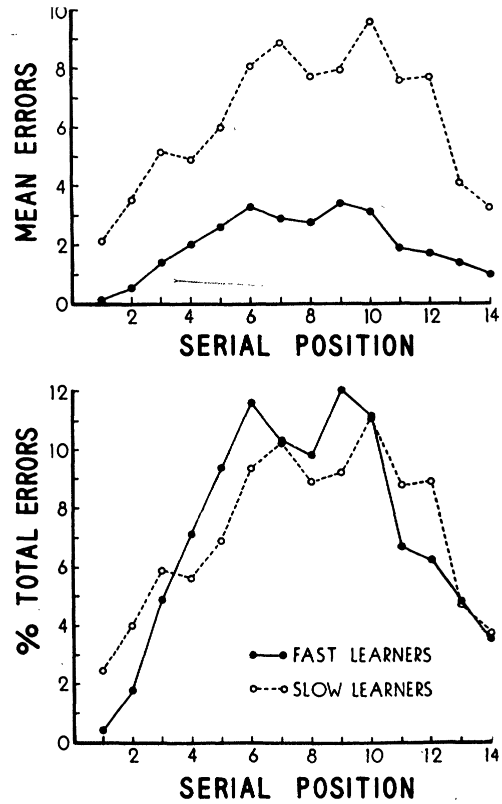

FIG. 5.

of errors made will result in a serial position curve of mean errors which lies below the curve for a less efficient method of learning. (2) The reduction in mean errors per serial position, although greatest in the middle or just past the middle of the series, will be closely proportional at each position to the total number of errors made. It is in no sense surprising that, when one changes from a less to a more efficient method of learning, the greatest reduction of errors will occur in the central serial positions. This is not a confirmation of the inhibition theory but merely an evidence of the fact that significant gains in efficiency can only occur where serious errors have been made—namely, in the central part of the series. It is surprising, however, that the gains under a more efficient learning method should be as proportionately distributed as the percentage curves indicate.

The theoretical problem still remains of explaining why the serial position curves for verbal learning are bow-shaped. We can offer no solution ourselves, although we believe that a multiple- rather than a single-factor theory will finally be indicated. The Lepley-Hull inhibition theory is plausible only under the conditions discussed above, where lapses of time were introduced into the learning process. In order to rank as an adequate general theory it would need to be shown that *any* condition which increased the efficiency of serial verbal learning (including meaning, familiarity, and quick learning ability) decreased proportionately the inhibitory tendencies postulated in connection with the various serial positions.

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An Electromagnetokinetic Phenomenon Involving Migration of Neutral Particles[1]

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Electrically neutral particles migrate in a magnetic field traversed by an electric current. The migration is perpendicular to the current and to the homogeneous magnetic field that is maintained at right angles to the current. If the electrical conductivity of the particles exceeds that of the surrounding conductive fluid, the particles migrate in the direction of the force exerted in the magnetic field upon the current. Particles of lesser conductivity than that of the surrounding fluid migrate in the opposite direction, whereas particles experience no force if their electric conductivity is equal to that of their environment.

The force of gravity, as well as the force of buoyancy exerted upon a suspended body, can be neutralized. For instance, an air bubble will not rise in acidulated water placed in a horizontal magnetic field of 10,000 oersteds traversed by a perpendicular horizontal current of 1 amp/cm^2.

Explanation of the effect. This effect is due to the establishment of a pressure gradient (analogous to the hydrostatic pressure gradient in the gravitational field) in an enclosed conductive fluid traversed by a homogeneous electric current and a homogeneous magnetic field perpendicular to that current. Each volume element of the fluid experiences a force perpendicular to the magnetic field and to the current of the magnitude

$$dF = (\mu H j)\,dV, \tag{1}$$

where μ is the magnetic permeability of the fluid, H the magnetic field strength, j the current density, and dV the fluid volume element. The force upon a finite volume V of arbitrary shape is

$$F = \int (\mu H j)\,dV = (\mu H j)\,V. \tag{2}$$

The expression $(\mu H j)$ corresponds to the specific weight in the hydrostatic analogy, and the force F to the weight of the volume ("electromagnetic weight," EMW). Since the fluid element V remains at rest despite the action of the force F, we conclude that an equal and opposite force is exerted upon it by the surrounding fluid. This force is comparable with the buoyancy in our hydrostatic analogy, being a consequence of the pressure field set up in the fluid by the interaction of the current with the magnetic field. We shall refer to this force as "electromagnetic buoyancy" (EMB). If the volume element V is occupied by a substance the electrical conductivity of which differs from that of the surrounding fluid, $EMW \neq EMB$ and the immersed body experiences an unbalanced force. In this case, however, a streaming of the fluid is engendered around the immersed object so that the hydrostatic forces alone do not suffice for a complete description of the effect. The following treatment is an approximation in which hydrodynamic effects are neglected.

Estimate of the force upon a sphere. The EMW of a sphere of conductivity σ_1, immersed in a fluid of conductivity σ_2 of infinite extent traversed by a homogeneous magnetic field and a perpendicular homogeneous electric current, can be estimated easily as follows: Maxwell (*Treatise on Electricity and Magnetism*, par. 313) has shown how to compute the electric field inside a sphere of conductivity σ_1 submerged in a fluid of conductivity σ_2 in which a homogeneous electric field of intensity E_2 is maintained. The electric field inside the sphere (E_1) is homogeneous and is given by the expression

$$E_1 = E_2 \frac{3\sigma_2}{2\sigma_2 + \sigma_1}. \tag{3}$$

The external field in the vicinity of the sphere is not homogeneous. Eq. (3) is valid strictly only if the sphere is negligibly small as compared to the extent of the surrounding fluid.

Eq. (3) can also be written as follows:

$$E_1\sigma_1 = E_2\sigma_2 \left(\frac{3\sigma_1}{2\sigma_2 + \sigma_1}\right). \tag{3a}$$

Since $E_1\sigma_1 = j_1$ and $E_2\sigma_2 = j_2$ are the current densities inside the sphere and in the medium, respectively, we obtain for the current density inside the sphere

$$j_1 = j_2 \left(\frac{3\sigma_1}{2\sigma_2 + \sigma_1}\right). \tag{4}$$

According to Eq. (2) the EMW of the sphere is

$$F' = \mu H j_1 V = \mu H j_2 V \left(\frac{3\sigma_1}{2\sigma_2 + \sigma_1}\right). \tag{5}$$

If we assume for the EMB exerted upon a submerged volume V the force (F'') given by Eq. (2) we obtain

$$F'' = \mu H j_2 V. \tag{2a}$$

Thus, we can write:

$$F' = F'' \left(\frac{3\sigma_1}{2\sigma_2 + \sigma_1}\right). \tag{5a}$$

The resultant force upon the sphere is

$$F = F' - F'' = F'' \left(\frac{3\sigma_1}{2\sigma_2 + \sigma_1} - 1\right) = \mu H j_2 V \left[\frac{2(\sigma_1 - \sigma_2)}{2\sigma_2 + \sigma_1}\right]. \tag{6}$$

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