CHAPTER 5

Verbal Learning

GORDON H. BOWER

Stanford University

Science is an intellectual discipline. That is to say, it is an enterprise which creates its own questions and problems, devises methods for attacking those problems, and along the way discovers yet more new questions and problems. The information gathered around an intellectual question is relevant and interesting only because of the question itself; pragmatic criteria regarding the utility of the information for other purposes (e.g., for constructing better teaching-machine programs) are secondary, indeed if they are considered at all. This is a fact about the sociology and ethics of science. Only by understanding the ethos and mores of an intellectual scientific discipline can one understand the diverse and myriad branchings, peculiar twists, turns, and intricate intertwavings, the fads, fancies, and foibles in the history of experimental studies of verbal learning. Although the title of the research area suggests it, most of the experimentation is not, in fact, concerned with the language learning of humans; otherwise, there would be more studies of language development in children or second-language learning in adults. Instead, the study of language functioning in the human has been left more to the province of other research areas, e.g., psycholinguistics. Since its inception, the research in verbal learning has held more kinship with the areas of conditioning or learning theory than with linguistics or child development. That is, the emphasis in verbal learning research has been more on the learning than on the verbal part of that descriptive phrase.

The founder of this branch of psychology was Ebbinghaus, dating from the publication of his treatise Über das Gedächtnis (Concerning Memory) in 1885. How does one found a new branch of science? By asking new questions and devising new methods for gathering reliable information to answer those questions. Because good questions tend to beget more and then more, the character of the developing science is molded to a considerable extent by the initial questions asked and the initial methods used to answer them. The influence of Ebbinghaus on the developing science of human verbal learning has been profound and pervasive (some would say devastating). Ebbinghaus created a new experimental situation in which a multitude of variables can and do act in concert in determining the behavior observed. One major job of the continuing research has been to tease out these variables, count them, measure them, determine their functional laws to the behavior of interest; and then modify the situation slightly and proceed to do the whole job over
again. In this way, a tremendous empirical backlog of information is accumulated about how human subjects learn verbal materials in experimental situations resembling the type created initially by Ebbinghaus.

As the empirical backlog accumulates around particular questions, local hypotheses take form which attempt to integrate the information into a reasonable schema, with a parsimony of terms and concepts, and possibly to lead to predictions about the outcome of experiments yet to be done. Given the doubting stance and ingenuity of most scientists, the act of making a hypothesis automatically begets at least one or two alternative hypotheses, which leads to more experimentation, and so on and on it goes. It has been claimed, by some of its critics, that research in verbal learning has been crassly empirical, to the point of being atheoretical. The plethora of local hypotheses to explain close-knit facts shows otherwise, if one simply counts noses of hypotheses. What the critic usually means is that investigators of verbal learning do not interpret their results in terms of theoretical concepts which the critic cherishes as being of global significance to interpretations of learning and behavior. The theoretical heritage of research in human learning has been the functionalism of Carr and Robinson (cf. Boring, 1950) and the analytic framework of stimulus-response associationism. But beyond this general framework, the structure and concepts of local hypotheses vary, as they should, depending upon the local requirements imposed by the particular facts to be explained. There have been few if any attempts to give a precise yet comprehensive theoretical integration of the facts from the whole area. The lack of global theories in verbal learning may be a blessing in disguise, because they tend to be more vague and/or contentious than useful for effecting orderliness in specific detail of data. For this latter job, local hypotheses seem called for and local hypotheses abound in the verbal learning field. There is a common core of concepts used throughout the area (e.g., similarity of units, meaningfulness, associative interference) but these appear to stem rather directly from the common stimulus-response-association framework within which nearly all the investigators interpret their findings.

The development of a science is like the expanding tail of a peacock, fanning out wider and wider in a number of directions. A given time slice taken across this development can count a number of distinct experimental situations or categories, each being studied more or less intensively, each having its own associated cluster of local hypotheses and experimental findings which attempt to answer the corresponding intellectual questions. The accelerated development and branching process of present-day research in verbal learning is enormous, enough so that a thorough-going review of all the material is a job beyond the capacity of sane men. The present review of this material is selective and incomplete, as are all reviews. For example, there is no coverage of the extensive literature on transfer of training and distribution of practice (cf. McGeogh and Irion, 1952). The general level and brevity of the review also enforces curtailing in coverage of the subtle details in experimental design and theoretical rhetoric so dear to the heart of the practicing researcher. The customary classification of problem areas will be followed, each area having its associated experimental techniques. The classifications to be covered in this chapter include studies of immediate memory, free recall, paired-associate learning, and serial learning; then a section on studies of forgetting, followed by a terminal section on reinforcement factors in human learning.

SHORT-TERM MEMORY

Experiments on immediate memory typically involve a single presentation of a small amount of information which the subject attempts to recall immediately. The classical experiments used sequences of decimal digits as the learning materials. Adult subjects can immediately recall seven or eight digits about 50 per cent of the time. This "digit span" is less for children, and it increases with age, which explains why it is incorporated in several IQ tests. In the digit-span test, the subject must recall the digits in the exact order in which they were presented. As might be expected, about half of the errors in recall are due to faulty ordering of the digits (Conrad, 1959).

Although untutored subjects have a digit span of around seven, the apparent span can be increased through recording devices. That is, via some dictionary, the original digits are encoded into a smaller number of information units by the learner (Miller, 1956). For example, if for binary digits the subject has established the dictionary \( A = 101, B = 001, \) etc., then the digit
string 001101 would be encoded as BA at the time of learning. Recall of BA, of course, enables the subject to translate back into digit strings via the dictionary. The apparent memory span that can be established in this way would seem to be limited only by the size and number of dictionary entries that a person can manage simultaneously.

One can make a conceptual distinction between the fact of storage of material and the ability to retrieve all this material in recall. Retrieval in recall takes time and possibly material yet to be recalled suffers further loss while prior material is being recalled. Thus, the digit span may give a spuriously low estimate of the amount of information in storage at a particular time. Sampling or cueing procedures for selective recall of portions of an entire message have yielded higher estimates of storage in Sperling's experiment (1960). Another method for measuring storage without involving retrieval is the missing digit span devised by Buschke (1962). In this test, the person listens to N-1 items in random order selected from a known set of N items, and then he indicates the one item which was not presented. In line with Sperling's results, Buschke found much higher estimates of retention with this procedure than with the alternate digit-span recall which measures both storage and retrieval.

A time-honored account of immediate recall supposes that the material presented activates a perseverating stimulus trace and, at recall, the person reads off the information from this internal image; hence, the appellation "memory trace." The trace fades and weakens in time, and it can be disrupted by intervening events. There is no doubt that short-term stimulus traces exist (Sperling, 1960; Mackworth, 1962). What is doubtful is that such stimulus traces per se have much relevance to recall of materials after intervals of more than one or two seconds (Sperling, 1960). At longer recall intervals, the subject apparently relies mainly upon remembering his implicit (verbal) encoding of the stimulus display (Haber, 1953; Harris and Haber, 1963). Encoding is the operation by which the subject constructs some internal representation of a stimulus at the time he sees it (Lawrence, 1963). In recall, he tends to recall only items that were encoded at the time of presentation.

A prominent line of recent research on immediate memory follows procedures devised by Brown (1958) and Peterson and Peterson (1959). Good reviews of this material are in Peterson (1963) and Melton (1963). In Peterson's studies, single verbal items are presented at a slow pace (e.g., two seconds each); the subject reads the item aloud and is tested for recall after a delay of several seconds. To prevent rehearsal, during the delay interval the subject is required to count backwards rapidly by threes from some random number provided to him. With this procedure, forgetting is considerable over only a few seconds. Results of one experiment with three-letter consonant syllables are shown in Fig. 5-1.

Suppose that the evocation of the subject's verbal response (by the material presented) is viewed as a trial of learning. Then one can distinguish certain antecedent stimulus events to which the verbal response is conditioned. One class of events are specific cues introduced by the experimenter as part of the materials. A strengthening of the conditional relationship between these cues and responses is called "cue learning" by Peterson (1963). Increasing dependencies between pairs of words in "paired-associate" learning is one example. A second example occurs with verbal items of very low initial integration (e.g., CHQ); cue learning would refer to strengthening of the interassociations between the letter units of such compound responses.

A second class of antecedent events identified by Peterson consists of background contextual
cues associated with the subject's situation. These may include, for example, internal cues from physiological processes, from postural adjustments and attitudes of the subject, from the experimental apparatus and physical surroundings of the subject, and so forth. Many of these cues are beyond the control of the experimenter. Strengthening of conditional relationships between these unspecified events and responses is called "background conditioning."

Each repetition of the verbal response can be viewed as producing an increment in background conditioning, and in cue learning to the extent that it is involved. The asymptote of the forgetting curve thus should be higher following more repetitions of the response. This prediction may be contrasted with the view that rehearsal only postpones the onset of decay of the memory trace but does not affect the characteristics of such decay once it starts. The effect of repetition was investigated by Peterson and Peterson (1960), and their results were extended by Hellyer (1962). Hellyer's results are shown in Fig. 5-2 illustrating the forgetting curves obtained following 1, 2, 4, and 8 repetitions of a consonant trigram before beginning the retention interval. The asymptote of the forgetting curve increases directly with number of repetitions.

The amount of cue learning required by a verbal unit will depend upon the number of subunits (letters) involved and the strength of pre-established interletter dependencies between the subunits. The effect of size of unit is shown in Fig. 5-3, obtained in an experiment by Melton, Crowder, and Wulff (in Melton, 1963). The units, either 1, 2, 3, 4, or 5 consonants in length, were presented once before the subject counted backwards by threes over the retention intervals shown in Fig. 5-3. Despite perfect immediate retention for the various-sized units, subsequent forgetting proceeded faster the greater was the amount of input information.

The effect on recall of preestablished associations among the subunits of an item has been shown by Peterson, Peterson, and Miller (1961) and by Murdock (1961b). Three-letter words are better recalled than three-letter nonsense syllables. The difference was due to the poorer integration of the syllables: subjects could often recall the first letter but not the remaining two. In fact, recall of first letters was equal for syllables and words. Because of prior interletter dependencies with the words, recall of the first letter was usually followed by recall of the remainder of the word. In brief, the syllable contained three chunks of information (Miller, 1957) whereas the word involved only one. When chunks are equated for sense and nonsense, as by comparing recall of three words with recall of a three-letter nonsense syllable, retention curves are similar (Murdock, 1961b).

Background conditioning would lead to interference when two verbal responses are learned, even though specific cues for them may be absent or differential. In one experiment (Peterson and Peterson, 1962), subjects studied two word-word
pairs in succession; in each pair, one word was the instructed cue to which the other word was to be associated. After a delay interval of counting backwards, the cue word of one of the pairs was presented and the subject tried to give the associated response word. Percentage correct recall on one of two presented pairs was consistently poorer than recall of a singly presented pair. The poorer performance was due in large part to errors of giving the uncalled-for response of the untasted cue word. Such "confusions" could result only from background conditioning since the cue words of the two pairs were dissimilar in all respects. As would be expected also, the more different responses conditioned to the background cues, the poorer the recall of any particular one. Murdock (1961a) showed this by varying the number of paired-associate items presented before and after a critical item that was later tested for recall. He found a decline in recall of the critical item as the number of prior and/or succeeding items increased.

If one assumes that background stimuli fluctuate over time in their effects on behavior, then an account of forgetting is obtained. Assume a large population of background stimuli partitioned at any moment into exclusive subsets which are (S) or are not (S') active, available and effective on the subject's performance. The verbal response is conditioned only to that subset of stimuli that are available and effective at the time the response is evoked by the presentation. Assume that over time the elements fluctuate randomly between S and S', like the diffusion of dye molecules between fluid compartments separated by a permeable membrane. At a recall test the available set of elements will be composed of some old conditioned elements and some new unconditioned elements, the extent of change varying exponentially over time since the initial presentation. The probability of the response on a test equals the proportion of available elements that are conditioned to it. From these assumptions, Estes (1955) derived the following equation to describe the time course of change in response probability. In Eq. 1, $p_n$ and $p'_n$ are the proportions of the elements in S and S' that are conditioned by the time the retention interval begins,

$$p(t) = p_n J + (1 - J)(1 - j - j')p'_n$$

as the probability of response after a delay interval of length t, J is the fraction of elements in the population that are in the available set, S, and j and j' are diffusion probabilities characterizing the fluctuation of elements between S and S' in each small unit of time. In the study by Peterson and Peterson (1959), a consonant syllable was presented only once, and hence $p'_n$ would be assumed to be zero. The equation fit to the results in Fig. 5-1 is $p(t) = .89[.01 + .99(.85)^t]$ in which t is in seconds, $p_n$ is .89, J is .01 and $f + j'$ is .15.

As mentioned earlier, the model predicts and one finds that repetition of the verbal response increases retention because $p'_n$ is larger with repetition. Suppose that we vary the time interval between the first and second evocation of the response, and ask how this interval will affect $p(t)$ in Eq. 1, where t is measured from the end of the second evocation. If the second reinforcement follows immediately upon the first before the set S has changed its constituency of elements, then very few new elements will be conditioned by the second reinforcement. If the second follows the first evocation by a long time, then many new elements will be conditioned by the second evocation. Thus, the longer the interval separating the two reinforcements, the greater the overall percentage of elements conditioned (i.e., $p_f + p'_n(1 - J)$ is greater). Hence, recall at t seconds after the second presentation should be higher the greater the interval between the two reinforcements. Peterson and Peterson (1960) confirmed this prediction using intervals of 1, 3, 6, or 11 seconds between presentations of the same nonsense syllable, and a 6-second interval between the second presentation and recall. Subjects counted backwards by threes during both intervals. Recall probability increased directly with the time separating the first and second presentation. The result has been repeated using paired-associate word pairs (Peterson, Saltzman, Hillner, and Land, 1962).

In Peterson's studies, recall of an item was measured after an interval during which the subject engaged in an interpolated activity. Murdock (1961b) has asked whether the forgetting is primarily a function of the time interval or of the amount of interpolated activity. He varied the presentation rate of interpolated material. Lists of 4, 7, 10, 13, 18, or 19 words were read at rates of 0.5, 1, or 2 words per second. The first word in the list was the critical one. It was always pre-
presented for one second; the remaining, interpolated items varied in number and in the time taken to be read to the subject. The subject was required to recall the first and last three words from each list immediately after the reading. Comparing recall of the first word in the various lists, Murdock found that the amount of interpolated material was the critical factor determining its retention. The presentation rate of the interpolated material, of course, determines the total delay interval between presentation of the first item and its test for recall, yet rate per se had little consistent influence on recall probability. These results are inconsistent with a fluctuation process which ascribes the turnover of background stimuli to events that occur at a constant rate in the fluctuation. The fluctuation itself must be tied to “set-breaking” interpolated activity rather than to the mere passage of time.

Recognition Measures of Memory

The experiments above used a recall test for retention. Shepard and Teghtsoonian (1961) have used a recognition index. Their subjects saw a long series of numbers, some being duplicates of ones presented earlier, and to each indicated whether it was an old or new number in the series. The probability of correctly recognizing an old number dropped rapidly from 1.00 to about .75 when up to seven items intervened between presentation and test. Beyond seven, the curve dropped more slowly, reaching a value of .57 after 50 intervening numbers. The curve departs from the exponential decay curve of fluctuation theory and Shepard (1961) has provided an alternative model for the process. The recognition probability of .57 reached after 50 interpolated items was still considerably higher than the probability of saying “old” to a new item, which increased to about .25 over the series. The difference in retention measures in this and Peterson’s studies (cf. Fig. 5-1) is likely due to the use of the recognition method. Much less information need be learned for recognition than for complete recall. For example, recall usually requires response integration whereas recognition does not. Additionally, the class of response alternatives is restricted in recognition (either yes-no or multiple choice) so that each correct response conveys less information than does the process of recall in which the response is being selected from a large set of possibilities. When the size of the selection set is equated, recall and recognition give quite equivalent outcomes (Davis, Sutherland, and Judd, 1961).

In the Shepard-Teghtsoonian procedure, the probability that the subject says “old” to an old item (“recognizes it”) will vary directly with its overall probability of saying “old” even to the novel items. Let \( P(O/O) \) and \( P(O/N) \) represent the conditional probabilities of the subject saying “old” to old and new items, respectively. Within the context of an experiment on signal detection in psychophysics (cf. Swets, Tanner, and Birdsall, 1961), \( P(O/O) \) would be identified as the “hit rate” and \( P(O/N) \) as the “false-alarm rate.” In signal-detection experiments, these two probabilities are known to covary systematically, tracing out what has been called the “Receiver Operating Characteristic” or ROC curve. Following the original work by Egan (1958), Galanter (Personal communication, 1962) has shown that the same two quantities covary in experiments on recognition probability with verbal items. Subjects were shown a list of \( L \) nonsense syllables which they were to learn. On the recognition test, \( K \) of these \( L \) syllables were randomly distributed throughout a list containing \( N \) new syllables. The subject checked for each syllable in the test list whether it was old or new. Before the test the subject was told the quantities \( K \) and \( N \), and thus he could establish a certain level of bias in his “old” responses. Using a variety of values of \( K \) and \( N \), Galanter found that the quantities \( P(O/O) \) and \( P(O/N) \) varied together, tracing out an ROC curve of the type found in signal-detection experiments.

In terms of the notions of Signal Detectability Theory (Swets, Tanner, and Birdsall, 1961), we may suppose that each test syllable produces a certain “feeling of familiarity” which varies in a more or less continuous manner, generally being higher for items read in the training list. Since the response required to each test syllable is a dichotomous “old” or “new,” the subject must partition the familiarity continuum into a region of acceptance and a region of rejection. This is done by selecting a criterion and calling an item “old” only if its familiarity exceeds the criterion. Given stable distributions on the continuum for old and new items, the selection of the criterion determines \( P(O/O) \) and \( P(O/N) \). As the criterion is varied, the quantities vary together. In Galanter’s experiment, prior information about the composition of the test list (\( K \) and \( N \)) presumably affected the
subject's setting of a criterion. For example, if $K$ is very large relative to $N$, then most items in the test list are old. Hence, the subject should set his criterion low, so that he reaches the decision "old" when uncertain about an item. The low criterion ensures a high hit rate, $P(O/O)$, but it also ensures a high false-alarm rate, $P(O/N)$, which was the experimental finding. Conversely, if $N$ is large relative to $K$, the criterion is set at a high value to reject the new items, with a resulting drop in the probability that old items are "recognized."

The application of detection theory to recognition learning seems a fruitful approach which will yield useful data. A number of experimental facts may be interpreted in line with the theory. For example, the average difference ($d'$) between the distributions of old and new items on the familiarity continuum should depend on (a) the similarity of the two sets of items (Postman, 1951), and (b) the number of presentations and the study time per presentation of the old items prior to test. Differential monetary payoffs for hits, false alarms, etc., would be expected to modify the subject's choice of a criterion. This approach also holds promise of being able to interrelate measures of learning obtained from yes-no and multiple-choice tests. One may question the assumption in this approach that the subject can make fine discriminations (and judgments) along a graded continuum of familiarity. However, Egan (1958) obtained results consistent with this assumption. Similarly, Nachmias and Sternberg (1963) obtained confirmatory results and, at the same time, were able to reject a model which assumed that the subject could make only two or three rough category judgments along the familiarity scale.

**FREE VERBAL RECALL.** In most of the studies reviewed above, the unit of presentation and test is the individual verbal item. New aspects come to light in studies of immediate "free recall," in which a list of words is read and the subject attempts to write down in any order as many words as he can remember. When the words are presented in random order, the items near the end of the list are recalled first and most frequently over a group of subjects (Deese and Kaufman, 1937). Such "recency" results would be expected on the basis of background conditioning since the available elements at immediate recall are those conditioned to the immediate preceding verbal responses.

Cue learning factors are major determinants of performance in free recall. If there are preestablished associations between words in the list, the words are recalled in associated clusters. Deese (1959a) indexed such preexperimental associations by tabulating the frequency with which subjects responded with another word in the list when asked to free-associate to each item of the list as a stimulus. The average interitem association scores for various lists correlated very highly with the percentage of words recalled after one presentation of the list. When a word was recalled, it appeared to act as a cue for its associates in the list. Rothkopf and Coke (1961) have added quantitative evidence on the increase in probability that a particular word would be recalled as the number of its cue associate words in the list was increased. Deese (1959b) has also found that nonlist words imported into the subject's recall could be predicted by the number of recalled words which were cues for the imported word.

A number of investigators (e.g., Miller, 1958; Garner, 1962) have stressed the relation between immediate memory and the information contained in the material to be memorized. Information is viewed in the technical sense of Shannon's mathematical theory (1948). The less information contained in the material the easier it is learned. For some (but not all) materials, the information measure is easily derived and the hypothesis can be tested. Adelson, Muckler, and Williams (1955) tested it by having their subjects recall strings of fifteen alphabetic letters in a fixed order. In one study, the number of different letters (2, 4, 6, or 15) composing the 15-letter sequence was varied. The information measure (uncertainty) for a 15-letter list is greater the more alternatives used and when the alternatives used are equiprobable. Information content can be reduced by introducing sequential dependencies between letters in the list (e.g., $d$ always follows $x$). The surprising result was that trials to learn a list was an invariant (linear) function of its amount of uncertainty whether the level of uncertainty was produced by manipulation of number of alternatives, the probability bias in the letters used, or nonrandom sequential dependencies between letters. Bower and Batchelder (unpublished) have replicated the essentials of this finding. Miller (1958) has reported further evidence on the facilitative effect of nonrandom sequential dependencies in letter sequences upon their free recall.

Miller and Selfridge (1950) have applied an
When unrelated words are used, it is known that individual learning curves averaged over the list in free recall have negative acceleration (Murdock, 1960a). However, Waugh (1961) finds that in serial recall, learning curves are linear. In Waugh's studies, a long list of words is read always in the same fixed order and the subject has to recall the words in the exact order. Though poorer on the early trials, subjects doing serial recall eventually catch and surpass subjects doing free recall (any order) of the same list of words. The linear learning curve for serial recall suggests that subjects acquired a constant number of new items per trial to ascend to those learned before, and that once an item was recalled, it was perfectly retained. Waugh's detailed results deviate slightly from this simple picture, but it is a good approximate description of what happens. The linear learning curve appears when recall is serial; free recall with fixed serial presentation of the words produces a negatively accelerated learning curve indistinguishable from free recall with random presentation orders.

If the average number of new words serially recalled per trial is a constant $m$ independent of the length of the list, then the trials to learn a serial list of length $L$ should be $L/m$. That is, a linear learning curve implies a linear relation between $L$ and trials to learn. Waugh (1962) confirmed this relation; she also validated the underlying assumption that $m$ was constant irrespective of the length of the list. Murdock (1960a) has found slightly different results with free recall. Suppose $k$ is an empirical constant (6.1 words in Murdock's study) and $R_1$ is the number of words freely recalled after a single presentation of a list of $L$ words at a presentation rate of $t$ seconds per word. Murdock found the following relation between these quantities:

$$\frac{R_1 - k}{L} = ht$$

where $h$ is a proportionality constant. Fixing presentation time, the percentage of freely recalled words exceeding $k$ is a constant independent of list length. In absolute terms, this means that $R_1$ increases with the product of $L$ and $t$. The effect of $t$ can be conceived in terms of the strength of the background conditioning of the words; the more time allotted to study a word, the more strongly it is conditioned. The effect of $L$ upon $R_1$ might be thought of in terms of increased op-
opportunities for cued associations; the more words learned, the more likely that some of them will have some cue-associative strength to later words to be recalled.

**Paired-Associate Learning**

In paired-associate learning (PAL), an explicit stimulus is provided for each response term. Normally a number of items are learned concurrently by the subject and training is by the anticipation method (i.e., stimulus presented, subject responds, show correct response). The order of the items is usually randomized from one presentation to the next to make serial cues unreliable bases for responding. The unit of analysis is the individual item, and the belief is that the learning characteristics of a list of N items are determined in a simple additive manner from the properties of the items composing it. The assumption is probably wrong in detail (c.f., Irion, 1959) but is close enough to serve as a convenient approximation and heuristic. Paired-associate learning has become increasingly popular probably because of its obvious face validity for the stimulus-response-association view that dominates research on human learning. The simplicity of the situation is only apparent, however, since the results rapidly become complex. To handle the complexities, recent theories (McGuire, 1961; Newman, 1961; Restle, 1964) have appealed to multiple processes which determine the course of PA learning. The three processes commonly assumed are stimulus discrimination, response learning, and association formation. An experiment by McGuire (1961) is exceptionally clear in illustrating these processes and, in addition, permits an assessment of the contribution of each factor to performance of the complex behavior exhibited in PAL. Here some of the material relating to each of the assumed processes will be reviewed.

**Discrimination** At the least, PAL involves multiple stimulus discrimination. Gibson (1940) recognized this and first applied to verbal learning the concepts of stimulus generalization and differentiation. If the stimulus members of two items are similar, the response learned to one will generalize to the other; confusion errors and possibly response blocking will result. Similarity of the stimuli in a list produces slower PAL (Gibson, 1942; Underwood, 1952; Shepard, 1958). The concept of similarity in this context has sometimes been attacked as vague, but in recent measurement models (Shepard, 1962) it is defined precisely enough in terms of distance between pairs of points (stimuli) located in a metric space.

In recent accounts, during discrimination, the subject is supposed to acquire mediating responses to the stimuli; these responses select or encode some aspect of the stimulus which distinguishes it from similar stimuli to which other responses must be made. Evidence that subjects in learning do encode stimuli, and then only partially, comes from studies of stimulus predifferentiation and of transfer following “concept” learning. The predifferentiation effect refers to the positive transfer produced by pretrained the subject to attend to discriminating aspects of the stimuli. The pretraining might consist simply of having the subject make active comparisons between similar stimuli and to notice in what ways they differ; later paired-associate learning of new responses to such stimuli proceeds faster than if the predifferentiating experience is absent (Gibson and Gibson, 1955; Goss, 1953). If the aspects that are used to distinguish the stimuli in the pretask are absent on the criterion task, no transfer is expected and none is obtained (Hake and Erickson, 1956). If the pretrained aspect is present but irrelevant in solving the criterion task, then negative transfer is obtained (Kurtz, 1955; Kendler and D’Amato, 1955).

Gibson’s ideas of stimulus and response differentiation have been formalized into an information-processing model of verbal learning by Feigenbaum and Simon (Feigenbaum, 1961). In their EPAM model, familiarization with the verbal items is represented as a process of adding test nodes to a discrimination net. Each node contains a test question (e.g., “What is the middle letter?”) followed by two or more further branches (to lower nodes) that are taken depending upon the outcome of the node’s test. Recognition of an item consists of sorting it through this network to some, perhaps temporary, terminal node. If two items are confused (sorted to the same terminus) when they should not be, then a difference between them is found and this difference is added as a further node at that point in the net. Stored at each terminal node (to which a stimulus is sorted) is a coded representation of the response item or the response image. The subject then attempts to retrieve the response item by sorting this coded information through the same discrimination network. If this process fails (the
model errors), then more response information is stored in the response image. Space does not permit further elaboration and interested readers should consult the Feigenbaum and Simon papers. This ambitious model has been realized in an IPL-V computer program, and the program has been run to simulate several classic verbal learning experiments. The fit of the model’s predictions to data have been extremely encouraging so far. Models of this type are likely to be playing increasingly important roles in the future as our theories of verbal learning become increasingly complex.

**Response learning.** Response learning refers to the possibility that the nominal response may itself be a novel chain of units that must be learned. In PAL with nonsense-syllable responses, the largest portion of the subject’s learning time is probably taken up with response integration. Typically, a preponderance of “errors” represent failures to respond, or incomplete or garbled versions of the appropriate response terms. To perform effectively, the subject must recall the units (letters), the serial order in which they occur, and he must overcome confusions with and interference from other novel strings of letters that are being learned concurrently to other stimuli in the list. His task might be called discriminated rote serial learning. Since serial learning is required with novel compound responses, letter-sequence habits acquired through familiarity with the English language can aid or hinder specific letter combinations; in information terms, a familiar sequence requires less new information to be learned.

The most potent factor controlling response learning is the meaningfulness and/or familiarity of the units. Meaningfulness is a difficult term to define, though Noble (1952, 1953) has proposed an operational index (number of associates, $m$) that parallels intuitive rankings. There is no claim that the number of associates gives the epistemic meaning of a verbal unit. The claim is that the index permits a lawful ordering of results on verbal learning, which is the major requisite for useful scientific concepts.

The effect of response-$m$ on serial and paired-associate learning is consistently large. More to the point, Parker and Noble (1960) demonstrated faster PAL when high $m$-values were artificially built into the response terms. Subjects were taught 0, 3, 6, or 9 arbitrary associations to paralogs (e.g., neglan, meardon) of initially low $m$-value. After pretraining, these paralogs were used as response terms in PAL; speed of learning an item increased with its induced $m$-value.

Extensive research on meaningfulness in verbal learning has been done by Underwood and Schulz (1960). They first report high intercorrelations among the following measures of three-letter verbal units (trigrams): frequency of occurrence in printed English text, rated familiarity, rated pronounceability, number of associates produced ($m$), and judgments of how difficult the unit would be to learn. They chose frequency of experience as the independent variable which underlies these intercorrelations and determines differences in verbal learning.

Underwood and Schulz propose a “spew” hypothesis to relate the frequency of experience with a verbal unit to the speed with which it is learned as a response. The hypothesis supposes that the order of availability and order of omission of verbal units is directly related to their frequency. Thus, input frequency determines speed and order of output. The hypothesis has derived prior support from experiments on verbal production. For example, Bousfield and Barclay (1950) asked subjects to produce all the names they could think of referring to objects in specific categories (bird, fruit, male names, etc.). The responses produced had high cultural commonalities and correlated highly with their frequency of occurrence in an English text. Moreover, the order in which the responses were produced by subjects paralleled their decreasing frequency of occurrence in the population. Common, high-frequency names were emitted first; esoteric productions occurred later. In PAL, Underwood and Schulz apply the spew hypothesis to the response learning phase: high-frequency verbal units become available sooner to the subject so that they can enter into associative connections to the stimulus terms.

In their experiments on response meaningfulness, Underwood and Schulz uncover some related facts about learning that are of general interest. For example, they report that in PAL requiring response learning, subjects quickly come to confine their overt responses to just those letters involved in the list responses; the remaining difficulties stem from interference between poorly integrated responses in the list. Such results suggest fast background conditioning of the response
elements followed by slower cue learning. The gradual learning and integration of letters (in nonsense trigram responses) over trials is shown clearly in Fig. 5-5. The abscissa in Fig. 5-5, generated value of the trigram, is a measure derived from interletter association frequencies. The higher the generated value, the less new cue learning required to integrate the response term. Another fact of some interest is that when the integrated response is first given, it is nearly always given to the correct stimulus. Thus, the primary measure affected by response meaningfulness is the trials required to emit the integrated response; in one experiment reported, this measure correlated — .98 with number correct in twenty trials.

Throughout a number of experiments varying the estimated preexperimental frequency of single letters, bigrams, and trigrams on the response side, Underwood and Schulz reported high correlations between frequency and learning rate. However, it was noted in the later trigram experiments that rated pronounceability of the unit correlated still higher with learning rate (correlations in the high .80's and .90's). Partialing out the pronounceability differences, the partial correlation between printed frequency and learning of trigrams was reduced to insignificant levels. However, firm conclusions regarding the relative potency for learning of various frequency measures, pronounceability ratings, and meaningfulness ratings of a verbal item will be hard to tease out. The measures are highly correlated in general, cases of discrepant ratings of an item on two scales occur rarely, and they are likely to be instances of unreliability of the measures. Thus, using their scales, Noble (1953) and Johnson (1962) came to different conclusions regarding the relative potency of these factors when they analyzed the Underwood and Schulz data.

Trigram frequency is important, by hypothesis, because the response term becomes available sooner for associative hookups. Thus, the beneficial

![Graph](image)

Fig. 5-5. Stages of learning with trigrams as responses as a function of generated values. The graph shows the average trial number on which various subparts of the response terms were given. "First correct" means the trial on which the complete response was given to the correct stimulus for the first time. (Underwood and Schulz, 1960)
effect on PAL of pretraining subjects on the response terms is ascribed to their earlier availability (Underwood, Runquist, and Schulz, 1959). But this is not the whole story; highly similar responses (i.e., nonsense syllables with many common letters) become available quickly but yet retard S-R associative learning because they are confused (Horowitz, 1961, 1962). Thus, prefamiliarizing subjects with the responses may produce positive transfer to PAL because the responses are better discriminated. Saltz (1961) had evidence for this in a study which obtained an effect of response prefamiliarization even though the responses were available (on cards) to the subjects during the criterion PA task.

Association formation Suppose the stimuli are well differentiated and the responses have become well-functioning units in the subject’s repertoire: how, then, does the subject come to hook up the response to the stimulus? If subjects are asked, most report the use of mediators that serve to organize the two terms. In learning the pair RZL-CAT, the subject may report that Z sounds like the hissing of a cat. Mnemonic devices of this sort are frequently used; they vary considerably within and between subjects in their content and elaborateness. With nonunitary stimuli, such as nonsense syllables, only one or a few aspects may enter the mnemonic. Mnemonic devices encode the material into “meaningful” relations that bring a person’s past associations to bear upon the acquisition of new materials. Items with reported mnemonics are learned faster than items for which none are reported. If several mnemonics relate aspects of the stimulus to the response, then recall probabilities are compounded. In connecting RZL-CAT, multiple mnemonics might be Z-hissing-cat, R-rat-cat, L-leopard-cat, RaZlLe-dazzle-CATtle, and so on. If organized mnemonics of this sort are learned, then so-called “backward” associations (giving the S term when shown the R term) are understandable. Backward recall depends on the integration of the nominal stimulus term (Murdock, 1956); poorly integrated stimuli lead to poor backward recall because the mnemonics encode only a few aspects of the full stimulus term.

If association is viewed in terms of the organization of the materials into mnemonics, then the relationship between the two terms (to be associated) is a contributing factor. Epstein, Rock, and Zuckerman (1960) have proposed that meaning-

ful terms are easier to learn because they are easier to organize into mnemonics. For example, pairs of concrete nouns (lamp–bottle) are easier to learn than pairs of abstract nouns, prepositions, conjunctions, and verbs, and the differences do not parallel differences in frequency of experience with the terms. If a small connective is inserted between concrete nouns to be associated (lamp—in–bottle), establishing a “sensible” relation, the associations are better learned. Similarly, learning is quicker if the two objects are shown perceptually in some kind of interaction (a picture of a hand plunged in a bowl of water). The perceptual coherence of the terms presumably affects the ease with which they become organized together.

Other studies have shown how ease of associating two terms depends upon their perceptual relationship at the time of presentation. Pairing of two figures is easily learned if (a) they “fit together” in some pictorial sense, e.g., a piece of pie, and a pie with a piece missing (Prentice and Asch, 1959), (b) one figure is a “good continuation” of the other (Kaswan, 1957), or (c) the terms form a unitary whole, e.g., beads are used to make an outline drawing of a teardrop (Asch, Ceraso, and Heimer, 1960). These studies on association and perceptual organization stem from the provocative writings of Kohler (1925). For Kohler, association was not a basic concept but rather a result of perceptual or cognitive organization. Some of the initial evidence (Kohler, 1941) offered for this view of learning has been cogently criticized by Postman and Riley (1957). The latter investigators showed that Kohler’s early results could be interpreted in terms of elementary stimulus and response factors without invoking notions of cognitive organization. It is doubtful, however, whether the same type of arguments extend to the experiments by Prentice and Asch, Kaswan, and Asch, Ceraso, and Heimer.

The study by Epstein, Rock, and Zuckerman (1960) attempted to show that the relation between the two terms affects their ease of becoming associated. Erickson (1963) demonstrated that if the specific relation between the stimulus and response term of an item is unique in the list, then the item is learned faster than the others. He offers this fact as a possible explanation for the von Restorff effect in PAL. This effect refers to the faster learning of an item that is different or isolated in some way from the other items in the list. For example, in the list below, the third
item has a different stimulus term than the other three items. It is routinely found that the isolated item is learned faster than the others.

\[
\begin{align*}
S-R & \quad S-R \\
CUY-MIH & \quad 375-KUX \\
DEQ-TIV & \quad YIK-ZAC
\end{align*}
\]

The effect is not peculiar to the odd term being in the stimulus position. The third item could be turned around, so that 375 is the response to KUX, and it still is learned faster than the others (Nachmias, Gleitman, and McKenna, 1961). The main efforts at explaining the isolation effect have utilized notions of stimulus or response generalization: that is, the isolated item is thought to be learned faster because it is subject to less generalization from the other stimulus-response connections being learned (e.g., Newman and Saltz, 1958).

Erickson’s experiment demonstrated that the isolation effect could be obtained simply by having a unique relation between the stimulus and response terms. The way in which this was done is schematized in the lists below. In both lists A and B, the third item is isolated because of the unique relationship between the S and R terms. In each case, it is learned more quickly than the other items. The result cannot be explained in terms of differential stimulus and/or response generalization favoring the unique item. On grounds of stimulus and response confusion, the isolated item should be learned slower than the other items (i.e., for the unique item, the stimulus and response could each be confused with two similar items, which is not true for any of the other items). Thus, the results

\[
\begin{align*}
\text{List A} & \quad \text{List B} \\
SWJ-217 & \quad SWJ-DXR \\
RKD-764 & \quad RKD-JPZ \\
KSC-2NH & \quad KSC-472 \\
186-DXR & \quad 186-217 \\
305-JPZ & \quad 305-764
\end{align*}
\]

lead to the conclusion that the rate of associating units depends upon the relationship between the two items.

The preceding discussion regarding meaningful mnemonics in PAL should be tempered, however, by evidence that some materials are learned without reportable mnemonics. The typical reply to queries is “I couldn’t think up any association for those two items, so I just memorized them by rote.” Although the question has not been investigated, we may presume that the probability that subjects use mnemonics will vary with the materials. In associating names of concrete objects, probably most learning is by mnemonics. On the other hand, Battig (1962) has reported low incidence of mnemonics when the task was to associate random nonsense figures with two-digit numbers. Because mnemonics utilize past associations, materials with reportable mnemonics are learned faster. The actual form of the learning curve may depend on this factor. Items susceptible to organization into mnemonics may be learned all at once when the mnemonic occurs to the subject; items without reported mnemonics may be acquired gradually. The distinction may be of use in the discussion of the next topic.

THE TIME COURSE OF ASSOCIATION FORMATION

The question is how to describe accurately the course of formation of an association over successive practice trials. If precise measurements could be made of the probability on each trial that a single stimulus evokes the correct response from a subject, what would this curve of response probability look like when plotted over successive practice trials? Would it increase gradually trial by trial or would it consist of one or more discrete jumps from one probability value to a higher one each level being maintained for several trials? The answer to this question cannot be obtained directly since the precise measurements cannot be made. On a single trial for a single S-R pair, we observe a success or an error, but neither gives sufficient information to infer much about the underlying response probability (except to know that it cannot be zero or one, respectively). Consequently, the attack on this question has been indirect. One assumes a particular answer to the question (a theoretical hypothesis) and then collects evidence relevant to the implications of the assumption.

The two opposing views on this question have been labeled incremental and all-or-none theory. As in most controversies, the caricature of the opposing point of view tends to become polarized, though logically there is a wide range of intermediate positions that can and have been taken on the theoretical continuum. A basic statement of an incremental theory is contained in the postulates of Hull (1943). The associative connection (habit, $ah$) between a stimulus and its reinforced
response varies in strength from zero to a maximum, increasing with each reinforced trial in a negatively accelerated fashion towards its maximum. The increase in \( sHR \) per trial is deterministic; probabilities enter later in the chain of reasoning. In Fig. 5-6 is shown graphically the hypothesized accumulation of excitatory potential (proportional to \( sHR \)) to an S-R connection resulting from successive practice trials. Inserted into Fig. 5-6 are two mechanisms that Hull assumed. One of these is the threshold for response evocation, \( sLR \); it was assumed that the habit had to exceed a threshold value before the response could occur. The second mechanism graphed in Fig. 5-6 is what Hull called "oscillatory inhibition." The true habit to an S-R connection was, on any trial, subjected to a randomly variable amount of inhibition, subtracting from the effective strength on that trial. The determinants of this oscillating inhibition were not specified by Hull, although others have assumed that it represents the effect of variability in the stimulus or in the stimulus-reception process. This random factor varies from moment to moment, yielding a normal distribution of values (the bell-shaped distributions in Fig. 5-6). At the moment the experimental stimulus is presented, a particular value of inhibition is present to subtract from the true habit strength.

The response rule of the theory is simple: If the momentary effective habit strength is above the threshold, the response occurs; otherwise not. This rule enables one to transform habit into response probability. The probability of the response is equal to the probability that the subtraction of the randomly variable inhibition from true habit yields a suprathreshold value. In Fig. 5-6, this probability is represented by the shaded portion of the bell-shaped normal distribution subtracting from the habit curve.

Hull's response rule is essentially that proposed earlier by Thurstone (1927) for handling psychological judgments. The threshold notion is taken over directly; the normal distribution of oscillatory inhibition is taken over from Thurstone's notion of "discriminative dispersion." The threshold and oscillation functions have no observational correlates; they are simply calculational devices, permitting one to translate \( sHR \) into statements about an observable, namely response probability. In Fig. 5-7 is shown the type of probability curve implied by the apparatus in Fig. 5-6; it is S-shaped between 0 and 1.00.

This theory is flexible. There are at least four unspecified parameters in Fig. 5-6 that can be varied to generate a variety of curve forms of the type illustrated in Fig. 5-7. The four parameters

![Graph showing the development of reaction potential over successive trials](image)

Fig. 5-6. The smooth curve represents the development of reaction potential over successive trials. The up-ended bell-shaped distributions represent the random oscillatory inhibition that may subtract from the true reaction potential on each trial. The area of this bell-shaped distribution that is above the threshold (\( sLR \)) is shaded. The shaded area represents the probability of the response on each trial. (Hull, 1943, p. 327)
are (1) the initial starting value of habit, (2) the rate at which habit increases over trials, (3) the value of the threshold, and (4) the range or variance of the oscillation function. If the habit starts high or if the threshold is low, then the resultant probability curve will be nearly negatively accelerated throughout rather than exhibiting the initial positive acceleration seen in Fig. 5-7. If the rate of learning is large relative to the range of oscillation, then the resultant probability curve will approximate a step function, going from zero to unity in essentially one trial. Because of the flexibility induced by the surplus of arbitrary parameters, the theory is difficult to disprove, which may account for its survival value.

The theory as presented is an oversimplification of the apparatus needed to make it relevant to, say, paired-associate learning. The discussion above refers to learning of a single stimulus-response connection in isolation. The normal paired-associate situation involves multiple stimulus-response pairs being learned concurrently. Thus, when calculating the course of performance on the pair $S_e$-$R_o$, one must consider (1) the generalized tendencies (habits) for $S_e$ to evoke responses to $R_b$, $R_o$, ... due to stimulus generalization from $S_b$, $S_o$, ... to $S_e$, and (2) the inhibition (see Hull, 1943) not to give responses $R_b$, $R_o$, ... to $S_e$, and the generalized inhibition (to $S_e$) of response $R_o$ to stimuli $S_b$, $S_o$, ... Also the response rule is changed because, to $S_e$, the subject has a net habit (sHr minus generalized inhibition) to make $R_o$ and generalized net habits to make $R_b$, $R_o$, ..., and these habits oscillate independently of one another. It is assumed that when $S_e$ is presented, whichever net habit is momentarily dominant determines the response if that habit is suprathreshold. When these modifications are added, the theory becomes unwieldy and the number of arbitrary parameters nearly exceeds the number of observations taken in the ordinary experiment. Some theorists (e.g., Runquist, 1962) have attempted to make enough simplifying assumptions so that the system can be used to analyze simple paired-associate data, but the quantitative predictions of the system have not been very rewarding in spite of the free parameters.

In lieu of this, the theoretical system has been used in practice as a qualitative source for explaining and ordering experimental results. A variety of qualitative predictions apparently follow from the theory. The qualifier "apparently" is inserted because the steps of the derivation from the expanded system appropriate to multiple paired-associate learning are usually not filled in. To illustrate the ambiguity of the theory on particular points, consider an example. Suppose a subject is learning paired associates with successive study (reinforced) trials and test trials (to stimuli alone). It has been claimed (Wollen, 1962; Battig, 1962; Williams, 1962) that the

![Fig. 5-7. Curve showing the theoretical probability of response over practice trials derived from Fig. 5-6. The values plotted are the proportions of the bell-shaped distribution exceeding the threshold value, i.e., shaded area in Fig. 5-6. The curve is a distorted S-shape with an elongated tail to the S. (Hull, 1943, pg. 331)]
theory implies that the probability of the first correct response following \( n \) consecutive errors (and reinforcements) to a given item should increase with \( n \). Data have been offered supporting this notion and it has been concluded that the theory was confirmed. But is it? The prediction does follow from the assumptions exhibited in Fig. 5-6 when considered by themselves. But consider the expanded theory necessary to take account of multiple learning of concurrent habits. First, in selecting items missed \( n \) times in a row (for calculating conditional probabilities), one selects differentially items whose parameters make for slower growth of habit. This selection will have an unknown effect on the outcome. Second, the greater \( n \) is, the stronger will be the generalized habits to make other responses to the reference stimulus term. Thus, although the correct habit is increasing in strength with trials, so also are the numbers and/or strengths of the generalized habits which lead to errors on the reference item. Depending upon the precise balancing between the parameters of these effects, it would seem that practically any prediction could be obtained from the theory regarding the point under investigation, viz., the way in which the conditional probability of the first correct response varies with the number of consecutive prior failures. Thus, in terms of the expanded theory, the prediction is ambiguous. Other sources of difficulty in deriving unambiguous predictions from Hull's theory for even simpler situations have been pointed out by Cotton (1959).

An alternative version of an incremental learning theory is contained in what has come to be called the linear model. The model stems from papers by Estes (1950), Bush and Mosteller (1951), and Estes and Burke (1953). The effect of practice is not conceived as affecting some hypothetical habit strength variable but rather operates directly upon response probabilities. Let \( p_n \) represent the probability of the correct response by a subject to some particular paired-associate item on its \( n \)th presentation. The effect of reinforcing the correct response on the \( n \)th presentation is to increase the probability of the correct response by a linear transformation, where \( \theta \) is a fraction between 0 and 1:

\[
\frac{p_{n+1}}{p_n} = 1 - \theta(1 - p_n) = \frac{1}{1 + \theta(1 - p_n)}
\]

(2)

The top line emphasizes the linearity of the transformation. The second line exhibits the assumption that the increment in probability (transforming \( p_n \) into \( p_{n+1} \)) is a constant fraction, \( \theta \), of the amount that the probability could have increased towards unity. By successively increasing the value of response probability according to the operator in Eq. 2, one obtains the general equation for \( p_n \):

\[
p_n = 1 - (1 - p_0)(1 - \theta)^{n-1}
\]

(3)

Several plots of Eq. 3 are shown in Fig. 5-8 where the learning rate parameter, \( \theta \), has the value .10, .20, or .30 and the initial probability \( p_0 \) is assumed to be zero.

The parameters of this theory are \( p_0 \) and \( \theta \). The initial probability, \( p_0 \), will vary with the availability of the response alternatives (i.e., whether they are integrated) and the number of alternatives. The learning rate, \( \theta \), would be expected to vary with the conditions promoting intralist interference. One advantage of the linear model is its computational ease, so that in its applications there is more emphasis upon fitting and/or predicting quantitative details of the data. A few illustrations applying the linear model to paired-associate learning have been published by Estes (1959a).

The alternative class of theories about learning have gone under the name of "all-or-none" theo-
ries. The single classificatory name does not, however, do justice to the broad range of possible models of this type (Estes, 1959b; Restle, 1964). The assumption is that the learning of a single item by a single subject can be characterized by a step function rather than a smoothly increasing curve. The various models differ in their assumptions regarding the number of steps (performance levels) and the laws governing transitions among the performance levels. Figures 5-9a to 5-9c illustrate some of the varieties of step-functions that have been proposed.

Figure 5-9a represents the most elementary form of the step models. It assumes that a subject-item combination can be characterized as being in either of two "states," with response probabilities \( p_0 \) and 1.00. The subject begins in state \( p_0 \); on each reinforced trial, there is some fixed probability \( c \) that the subject learns the appropriate association. The models exhibited in Figs. 5-9b and 5-9c differ in that they identify one or more intermediate stages in learning, intervening between the starting value \( p_0 \) and the terminal asymptote of unity. The appropriate mathematical representation of each of these theories is a finite Markov chain. The states of the Markov chain are the different levels of response probability, and the learning rate parameters represent the probability of a transition from one state to the next. Because finite Markov chains have been well analyzed mathematically, it is a simple matter to derive predictions for a variety of features of a given set of experimental results.

Because of the uniqueness and vulnerability of the elementary one-step model in Fig. 5-9a (with constant probability \( c \) of a transition), much experimentation on the "incremental versus all-or-none" issue has concentrated on this model. The implicit ideas were first suggested by Rock (1957) to account for some of his experimental results; subsequently, Estes (1959b, 1961) and Bower (1961a, 1962a) gave mathematical statements to the theory and added corroborating evidence.

The experiments stemming from Rock's work will be discussed first since they have chronological priority. In the basic experiment, two conditions of PAL were compared. In a control condition, subjects learned twelve randomly selected letter-number pairs by repeated study-test trial cycles: on study trials, each S-R pair was shown for five seconds; on test trials the S term was shown, the subject tried to provide the R term, and he was given no information regarding the correct response. The same twelve pairs were repeated through a number of study-test trial cycles until the subject answered all twelve items correctly in one trial. In the experimental condition, Rock adopted the novel procedure of replacing with new items those items the subject missed on each test trial. Each subject in this replacement group was continued until he achieved one errorless test on the twelve items presented on the previous study trial.

Rock's rather surprising finding was that the mean learning curve and average trials to reach criterion were nearly identical for the repetition and replacement groups. He concluded that a repeated reinforcement to a missed item must have had about the same effect as the first reinforce-

![Fig. 5-9. Some examples of step functions to describe acquisition of single S-R associations. Figs. (a), (b), and (c) show, respectively, one, two, or three steps to the acquisition process. The probability of a one-trial transition to the next higher step is indicated beside the directed arrows. The number of trials during which performance is at a particular level before the next jump randomly varies across subjects.](image-url)
ment to a new (replacement) item. Other things being equal, the results were inconsistent with an incremental theory and consistent with the assumption of one-trial learning, with the probability of learning being constant independent of the number of prior repetitions and failures to learn.

The question, of course, is whether "other things are equal" for the repetition and replacement groups. Specifically, there is the possibility that subjects in the replacement group are at a favorable advantage because the procedure differentially removes the difficult items, so they are likely to end up with an easier list of items. Rock recognized this possibility and performed several experiments attempting to reduce or eliminate selection artifacts (Rock, 1957; Rock and Heimer, 1959). Further experiments (Wogan and Waters, 1959; Clark, Lansford, and Dallenbach, 1960) yielded essentially the same conclusion as did Rock's first study. The question has been raised, however, whether these experimental controls on item selection have succeeded (Postman, 1962), and there have recently been reported a number of attempts to assess the amount of item selection induced by the replacement procedure.

The theme of these subsequent evaluations can be seen in an experiment by Williams (1961). Using Rock's materials and methods, Williams first replicated Rock's finding of nearly equal trials to criterion for control and replacement groups. Secondly, she asked whether the final items for a replacement subject were easier than the randomly selected items learned by control subjects. To assess this, she had a yoked control subject learn by repetition the final list arrived at by a replacement subject. Such yoked-list control subjects learned in significantly fewer trials than either of the other two groups. Thus, the replacement subjects apparently were eliminating the difficult items and ending up with an easier list on the average. The easy items appeared to be those with responses among the lower numbers (1-15), suggesting that response differentiation (Saltz, 1961) was the responsible factor. From these results, one may conclude that the replacement procedure induces selection of easy items. A subsequent experiment by Underwood, Rehula, and Keppel (1962) arrived at similar conclusions regarding item selection. Thus, the implicating force of Rock's initial results for incremental theory have been lessened. Still one may note that Rock's replacement subjects did learn in "one trial" in the descriptive sense that an item was replaced unless it showed a one-trial transition to 100 per cent correct responding. Some may also feel that somewhat implausible coincidences must be invoked to argue that the item selection (for replacement subjects) occurs in just the right amount to offset the benefit of repetition (for control subjects).

Related experiments have attempted to assess the benefits of repetition for individual items that have been missed a few times. The implication of the simple all-or-none model in Fig. 5-9a is that the conditional probability of a success following n consecutive failures to an item will be a constant, \( c + (1 - c) p_e \). Experiments by Wollen, Battig, and Williams (reviewed earlier) showed that this prediction was false for their types of learning materials; in their studies, this conditional probability increased with the number of prior reinforcements (and failures). The results are consistent with the one-step model (Fig. 5-9a) which assumes that \( c \) increases over trials due to warm-up, learning to recall the responses, or whatnot. They are also consistent with a one-step model which assumes an asymptote slightly less than unity. Furthermore, they are also consistent with the two-step model in Fig. 5-9b or with the linear model. As typically happens with experiments on this issue, the simple model rejected by the data is reasonably clear; the alternative model confirmed by the data is not clear since no alternative is put to a stringent test.

A second series of experiments surrounding the incremental versus all-or-none issue was initiated by Estes (1960, 1961) and Estes, Hopkins, and Crothers (1960). Estes noted that in elementary form the two theories differ in their predictions concerning the repetition and alternation of responses over a series of unreinforced test trials. Suppose a single reinforcement is given to a number of S-R pairs, followed by two test trials on which there is no information to the subject concerning the correct response. Let 1 represent a correct response and 0 a failure. Then over the two test trials we will observe either 11, 10, 01, or 00 for each sequence (subject-item). Let \( p_{10} \) represent the respective joint probabilities. One implication of the linear model is that \( p_{10} \) should equal \( p_{01} \); that is, the number of alternations from success to failure should be balanced by those
VERBAL LEARNING

from failure to success. Estes (1961) has shown that the prediction follows even though it is assumed that (a) the effect of the reinforcement varies over sequences, and (b) the response occurring on the first test is increased in probability (by a linear transposition) by an amount varying over sequences. These are rather general conditions. The initial evidence presented on this issue by Estes was not in accord with these predictions; specifically, $p_{10}$ was considerably larger than $p_{01}$. Results of a similar kind have been reported by others. The results were consistent with an all-or-none model which invoked some forgetting of correct responses between the two test trials. However, this evidence has been put in doubt recently due to some results by Postman (1963). In eight different PA conditions with the double-test design, Postman found the alternation probabilities, $p_{10}$ and $p_{01}$, were about equal. Thus, research is needed to specify the causes for the discrepancy. One factor affecting the frequency of alternations is the time permitted the subject to get out a response on test trials (the exposure time). The writer has found the proportion of alternations ($p_{10} + p_{01}$) to be between four and five times larger with brief (1.25 seconds) than with long (10 seconds) exposure times on test trials. The influence of exposure time on the results is an ancillary performance effect easily incorporated into either model. Until new experiments clarify the facts, however, the RTT evidence is presently ambiguous on the theoretical issue.

Another methodological attack on the incremental versus all-or-none issue has been employed by Suppes and Ginsberg (1961) and Bower (1962b). The procedure consists of examining backwards learning curves to see whether they are horizontal. A backwards curve (Hayes, 1953) is obtained by averaging responses from each sequence 1, 2, 3, ... trials back from the last error on each sequence. Alternatively, one may plot a forward “prelearning” curve starting from trial 1 by using on each trial only those sequences for which the last error occurred on a later trial. If the one-step process of Fig. 5-9a is a proper description of the data, then the prelearning curve will be horizontal, i.e., a constant level of response probability, $p_0$, over trials prior to the last error on each sequence. This result would be obtained even though the probability of learning (going from $p_0$ to 1.00) was increasing with trials. Incremental theories would not predict flat backwards learning curves, regardless of differences in learning rates of subjects and/or items averaged together in the curve. A number of Monte Carlo runs (cf. Bush and Mosteller, 1955) with the linear model the writer demonstrated this with several plausible distributions (over the subjects and items) of learning rates.

Initial tests of this prediction for verbal learning situations involving two response alternatives gave encouraging results for the all-or-none theory (Suppes and Ginsberg, 1961; Bower, 1962b). Figure 5-10a shows some results from two-response PAL and Fig. 5-10b shows results from a two-choice verbal discrimination learning task. Both exhibit the requisite stationarity of response probability prior to the last error. The smooth increasing curves at the top of Figs. 5-10a and 5-10b are the trial by trial probabilities of correct responses averaged over all sequences. The gradually increasing curves apparently result from averaging together sequences for which the jump in probability occurs at different trials. Bower and Trabasso (1964) have shown similar data for two-category concept identification experiments.

It should be pointed out immediately that such stationary prelearning curves are frequently not obtained under slightly more complicated experimental situations. This could result for several reasons. One possibility is that the one-step model is basically right, but that in some conditions the terminal probability of a correct response is less than unity (say .97). In this case, empirical backwards curves from the alleged point of the “last error” (before a list criterion) would not be expected to be stationary. A second possibility is that two or more performance stages are encountered during acquisition. The nonstationary results encountered so far are easily handled by the two-step model in Fig. 5-9b, which assumes an intermediate performance level. The strategy adopted by the writer is to determine the experimental conditions under which stationarity is obtained. Effectively, these conditions amount to a relatively small subset of the experimental arrangements customarily studied in PAL. That is, it is a relatively easy matter to complicate the situation so that stationarity is violated. The theoretical strategy has been to begin with the elementary all-or-none idea as a fundamental base, and to handle various complicating factors by compound-
Fig. 5-10. Prelearning curves for paired associates (a) and verbal discrimination (b) learning. The chance probability of a correct response is .50. The lower points represent the proportion of correct responses over those sequences for which the last error has not yet occurred. The upper curves are the obtained and predicted proportions of correct responses averaged over all sequences whether or not their last error has occurred on some earlier trials. The theoretical function fit to these data is $p_n = 1 - 5(1-c)^n$, where $c = .344$ and .252 in Figs. (a) and (b), respectively.

A second experiment by Bower and Levine (reported in Restle, 1964) found that the extent to which the results deviated from a simple one-step description varied directly with the opportunity for stimulus confusions. The stimuli consisted of three Korean characters, and they were paired with common English nouns. With a twelve-item list, clusters of three items had common characters but differed from all other clusters. The clusters had either 0, 1, 2, or 3 common Korean characters; when there were three common characters, the stimuli within the cluster varied in the left-to-right order of the characters (i.e., $abc$, $bac$, $cab$). The principal results were that the percentage of sequences within a cluster having a reversal (i.e., at least one error following the first correct) increased almost linearly with the number of common characters in the cluster. In the extreme cases, with no common characters (high discriminability) the percentage reversals was only 1 per cent and the results were fit well by a simple one-step learning function; with three
common characters, the percentage reversals was 34 per cent and the one-step model was rejected.

Restle's analysis of these data supposes that there are two stages to learning. The first stage consists of conditioning the responses to certain aspects of the stimuli. If that aspect differentiates the stimulus from other stimuli, then the learning is over (one step). If the aspect is not differential, then stimuli with common aspects will be confused and generalization errors will occur. The second stage Restle identifies with the subject discriminating between confusable stimuli, eventually selecting a differential aspect by trial and error. The probability that the "confusion" state is entered at all depends on the similarity of the stimuli, as does the probability of leaving the second stage (completing learning) if it is entered. Each stage proceeds in an all-or-nothing manner. However, the result of convoluting two all-or-nothing processes is a two-step individual learning curve. If there are four known responses, then the initial probability of a correct response will be near .25. If two stimuli in the list are confused with one another, then when the second stage is entered, response probability to these stimuli jumps to .50 for several trials, and thence to unity when the discrimination is solved. The instances in which the model predicts a one-step learning function arise when (a) the stimuli are dissimilar so that confusion errors are minimized, or (b) there are just two response alternatives.

The latter happens because one obtains an average correct response probability of .50 whether the subject is just guessing (stage 1) or is confusing similar stimuli with different responses (stage 2).

The other complicating factor mentioned above was that of response learning, in the sense of integration and recall of the response terms. Satisfactory extensions of the multistage model are not available presently to account for the response learning factor. One perplexing problem is to identify what should be the appropriate unit of the response to which the theory is to be applied. Suppose the responses are paired consonants such as JW, FB, etc. One may think of the two letters of each response and their order becoming separately associated with the stimulus member. If the learning of each letter and their order each proceeds on an all-or-none basis, then the resultant learning sequence for the compound response JW will not appear to be all-or-none in form. These ideas, suggested by the work of Crothers (1962), have been worked out in detail elsewhere (Bower, 1961c). The writer has carried out several experiments to show the feasibility of this line of argument. In one study, the response compounds consisted of two components, A or B and 1 or 2, making four compounds AI, A2, B1, B2. These compound responses were assigned equally often in a twenty-item PA list which subjects learned. Separate analyses of the component

Fig. 5-11. Preliminary curves for the A-B component (11a), the I-2 component (11b), and the entire compound response (11c). The component proportions fluctuate around .50. The proportion of correct compound responses increases from .25 towards .50 over successive trials before the last error on the response compound.
response sequence indicated that the learning of each component was an all-or-none process (cf. Figs. 5-11a and 5-11b). However, counting corrects only if both components were correct, the results for learning of the compound responses were not stationary (Fig. 5-11c). Probability of a correct compound response rises towards .50 over trials before the last error on the compound. This rise is evidently due to those cases in which one component is learned before the other; the rise in Fig. 5-11c is gradual because of averaging across sequences for which this jump from .25 to .50 occurs at different trials.

If only the results on the compound responses (Fig. 5-11c) were available, one would conclude that we are observing a gradual learning process. However, the component results in Fig. 5-11a and 5-11b suggest how the gradual compound curve arises from more basic all-or-none changes. Such data illustrate at an elementary level how compounds of molecular all-or-nothing learning processes can produce molar results which appear gradual in their major features. Similar results have been reported by Bower and Theios (1964) and by Kintoch (1962). The implication of these data is that the appropriate model to handle response learning will probably depend on the unit of analysis involved. The results cited above are, however, only programmatic, and much work remains in developing multistage models to handle response learning.

To summarize, then, this extended discussion concerning the course of acquisition, the initial promise of the simple all-or-none model as a complete description of learning failed, almost of necessity; a variety of results can and have been marshaled against it, and it appears to work well only under extremely restrictive circumstances. This state of affairs has led to the formulation of multistage models of learning, each stage associated with one or another source of difficulty for a subject learning a list of paired associates. The multistage models, especially those with only two or three stages, are mathematically tractable, so that details of the data can be predicted and quantitative tests of differential assumptions can be effected. The theory assumes that each stage is passed in an all-or-nothing fashion, and the passage (learning) parameters reflect how much difficulty subjects have with particular aspects of their total learning problem. Whether a two-stage model really differs much from an incremental model is a question best left to a practicing semanticist. The assumptions appear different and a number of its predictions differ from that of a continuous-growth model. Some of these are detailed in the papers by Bower and Theios (1964) and Restle (1964).

**Serial Learning**

One of the basic facts about behavior is that it is serially organized. The consequences of behavior typically depend not only upon which responses are made but also upon the order in which they occur. For conceptual analyses, a stream of behavior is broken into a chain of relatively discrete responses, with each response in the chain producing the cues for the next response. The importance of sequential orderings in behavior has motivated a substantial amount of research on serial learning. We will review some of the experiments on serial learning of verbal units.

Experiments on serial learning (SL) with verbal materials have come to have a reasonably standard methodology. A list of verbal items are displayed one at a time in a fixed order, frequently by a mechanical exposure device like a memory drum. In the classical anticipation method, the subject uses the item presented as a signal to anticipate the following item in the series. After a fixed time, the next item is exposed. Thus, each trial is successively a learning and a test trial. Also, each item serves in turn as a response (to the preceding item) and a stimulus (for the succeeding item). After the last item is exposed, there is a brief rest (intertrial interval) and then the subject starts over again at the beginning of the list.

The SL task can be viewed as having two distinct parts: learning and integrating the items as responses, and learning to arrange these items in the correct serial order. Factors affecting response learning have corresponding effects on the rate of SL. Thus, more meaningful lists of items are learned faster in SL and prefamiliarization with the items facilitates later SL. The studies to be reviewed are concerned more with the ordering task in SL and the factors that affect it. Under this label we will review work on remote associations, the serial position curve, and the effective stimulus for the response in SL. These are interesting phenomena unique to the SL arrangement and have stimulated much research.
VERBAL LEARNING

We begin with the phenomena of remote associations since they lead into the other topics. The phrase "remote associations" refers to list responses that occur in the wrong position—an example of labeling a phenomenon by the theoretical concept used to explain it. Such intrusion errors are classified as to their degree of remoteness. Bugelski (1950) reported that anticipatory errors of n degrees of remoteness decline exponentially with n. One can identify several variables that produce such errors of ordering, with intralist similarity and preestablished interitem associations being the more prominent ones. Following the analysis of Gibson (1940), if two items at separate list positions are similar, then intrusion errors will result because of confusing them when they act as stimuli and when they act as responses. Preestablished interitem associations are obviously important sources of some intrusion errors; thus, in the word series bread-chair-butter . . . , the preestablished association bread-butter will interfere with the first-order association bread-chair which is to be learned. But remote associations are also in evidence and follow certain laws even for list materials that have no formal similarity or preestablished interitem associations. Hence, additional factors inherent in the SL task must be identified as the causes of remote intrusion errors in such lists.

One of the interesting facts about SL is that the rate of learning an item depends upon its position in the serial list. Figure 5-12 shows a characteristic serial position error curve; items at the beginning and end of the list are learned fastest, while items just beyond the middle are the most difficult. The relative shape of such serial position error curves seems to be invariant over changes in certain variables that affect overall learning rate on the list, e.g., meaningfulness, presentation rate, intertrial interval (McCrary and Hunter, 1953). The absolute number of errors varies with such factors, but the relative percentage of all errors that are attributable to errors at each position yields pretty much the same curve. Because of the appealing simplicity of this invariance, a number of theorists have tried their hand at explaining it. Some of these efforts will be touched upon in the subsequent discussion.

THE EFFECTIVE STIMULUS IN SERIAL LEARNING

Theoretical analyses of serial learning have proceeded on the intuitively natural assumption that the effective stimulus for the subject to emit, say, item 7 as a response is the stimulus complex consisting of the preceding item 6 and possibly traces from more remote items 5, 4, . . . . This has been called the "specificity" hypothesis. Because of the obvious face validity of the assumption, it has gone essentially unquestioned for many years. Consequently, the results of some recent experiments by Young (1959, 1961) came as a jar to these preconceptions. Young noted that the specificity hypothesis predicts high positive transfer from SL to a PA task in which pairs are adjacent items from the serial list. After learning the serial list ABCDE, subjects were trained on a PA list containing the pairs A-B, B-C, C-D, D-E presented in the random order characteristic of PAL. Young found very little of the expected high positive transfer. Some positive transfer was evident early in PA learning, but it disappeared so that experimental and control groups reached criterion on the PA task in about the same number of trials. A related experiment (Young, 1962) assessed transfer to a PA task in which the stimuli were the two preceding items of the prelearned serial list, i.e., AB-C, BC-D, etc. Again there was no evidence for positive transfer because of learning these items in the prior serial learning task. Thus, a simple prediction from the specificity hypothesis was disconfirmed.

An alternative view of SL identifies the position

![Figure 5-12. Errors at each serial position in the learning of a twelve-item serial list of nonsense syllables to a criterion of mastery. The score is actually the average number of trials on which the item was not given correctly and includes failures to respond. (Hovland, 1938)]
of an item in a temporal series as the effective cue for that item. Call this the “position” hypothesis. Serial position can be identified with some accuracy (Schulz, 1955); in fact, after SL, errors in identifying the correct position of an item show the typical bowed serial position curve. Initially, the discrimination may be rough, in terms of whether an item is near the beginning, middle, or end of the list. Later the discrimination may be sharpened by actually labeling the items by their ordinal position in the series.

Ebenholtz (1963a) has further evidence against the specificity hypothesis and favoring the position hypothesis. In one experiment, items occurred in a fixed sequence but not in fixed ordinal positions. A list can be viewed as a continuous cycle without beginning or end. Each trial was started at a different place in the cycle, and the subject went through the successive items of the cycle until he came back to the starting point of that trial. With this method of random starting points, subjects took about twice as long to learn as when item positions were fixed as in the conventional method of presentation. The random-starting-point procedure forces subjects to learn via sequential associations; fixed starting points permit the use of serial position cues as well. It is of interest to note that many of the subjects reported that they learned the cycled list by selecting a particular item as an “anchor point” or subjective beginning of the list, and then learned items around that anchor point.

A second experiment by Ebenholtz (1963a) investigated transfer between two successive serial lists, the second list containing several items from the first. It was found that the old items are readily learned in the second list if they retained their old positions in the series; if their positions were changed, then the old items were not learned any faster than the new items unique to the second list. The specificity hypothesis would have predicted negative transfer on the second list because of associative interference, i.e., the old items in the new list, having been initially connected to their adjacent old items, should create difficulties when new responses (of the second list) must be connected to these same stimuli.

In a third experiment, Ebenholtz (1963b) obtained high positive transfer between a temporal serial task and a PA task in which the stimuli were spatial positions. By the PA method, subjects learned to associate verbal responses with position cues (ten small windows in a vertical column), these cues occurring in a random temporal order. Following this, they learned a temporal list of these verbal items in which the temporal position of an item corresponded to its spatial position in the prior PA task. For example, the second item in the temporal series was the one associated with the second spatial location in the random-presentation PA task. Nearly perfect transfer was obtained between this PA task and its corresponding temporal serial task.

An interesting datum reported by Ebenholtz was the spatial position error curve for the PA task with spatial locations as cues. This position error curve was very similar in form to the bowed-shape position curve obtained in temporal serial learning. That is, fewest errors occurred on the cues at the ends of the spatial continuum and most errors occurred on cues near the middle of the continuum. This fact suggests that the error curve in temporal serial learning is but one variety of position effects obtained whenever the stimuli are arranged along an ordered dimension. This idea has been developed formally by Murdock (1960b) in a paper dealing with the distinctiveness of stimuli varying along a single stimulus dimension. He reported experiments on PAL with stimuli ordered along a variety of continua and found that the end stimuli were easiest to learn and the middle stimuli in the series were the most difficult.

The conclusion from these studies by Ebenholtz and Murdock is that ordinal position is an effective stimulus in SL and further that the serial position error curve results from natural differences in the cue distinctiveness of the various serial positions. According to this view, “remote association” intrusion errors result from confusions in the location of the unlearned items in the series. If a subject learns a general location for an item before he learns its specific location, then intrusion errors of several steps remoteness would not be as likely as those of one or two steps remoteness. Thus, the grade of remote association errors reported by Bugelski (1950) would be explained. The position cue hypothesis may also be extended to handle other results of SL. For example, it is usually found that lengthening the rest period between trials increases the rate of learning in SL. A possible explanation is that the longer break between trials enables the subject to identify more clearly the beginning and end terms of the series,
thus aiding position learning. In the extreme case, when there is no break between the last and first items, positions cannot be identified and it is a difficult task to learn (Eysenck, 1959).

A middle ground on the specificity versus position-cue issue will probably prevail among experimenters in verbal learning. The possible cues for the response in serial learning may be its serial position, the prior item, or a cluster of several prior items. The job for continuing research is to determine the conditions under which these cues take on different relative weights in the complex stimulus pattern that controls serial responses. It is highly probable that the relative weights of these various cues will depend on the nature of the verbal items composing the serial list. For example, if the items are very similar to one another, then cues from prior items are not distinctive and this may increase the relative weight of position cues.

An alternative theory of the serial position effect has been proposed recently, apparently independently, by Jensen (1962b) and by Feigenbaum and Simon (1962), and the resultant ordering of the data is attractive. Jensen’s exposition will be outlined in the following. He assumes that the item learned first is usually the one to which the subject first attends, or in fact the first item in the list. This first learned item then serves as an “anchor point” for the remainder of the list. It is assumed further that the subject learns most readily by attaching new responses to previously learned responses. This implies that items are learned around the anchor point, both in a forward and backward direction. The order of learning is illustrated below with a series of nine items being folded around the anchor point (item 1).

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

In terms of the order of learning, from first to last, the predicted order is items 1, 2, 9, 3, 8, 4, 7, 5, 6. The rule for generating the predicted series for any length list is to start with the first two items and then alternate successive terms in from the end of the series and away from the beginning of the series. This notion for predicting serial position difficulty appears to be quite valid; the average correlation between rank of predicted position difficulty and obtained errors was about .97 over some 70 serial position error curves that Jensen collated from the experimental literature.

For example, for the Hovland data (1938) shown in Fig. 5-12, Jensen’s rule predicts the rank of error scores with only one slight disordering (items 6 and 9 are reversed from predicted). The fit of the theory is about as high as the reliability of the serial position curves obtained in different studies.

Jensen takes this theory several steps further. Given that the items are going to be learned in a particular order, assume that once the subject arrives at the point where he is to learn the nth item, the time it takes him is constant. Suppose further that each item is learned in one trial in an all-or-none fashion. Then the proportion of the total errors contributed by a given position should be equal to the rank order in which that position is learned divided by $1 + 2 + 3 + \ldots + N$, where $N$ is the number of items in the series. An outcome of this idea is that the shape of the relative percentage error curve (over serial positions) is invariant over changes in the overall learning rate on the list. This accords with the observation of McCrory and Hunter (1953). The predictions of the relative error percentages by this hypothesis corresponds closely to the data reported by McCrory and Hunter (cf. Feigenbaum and Simon, 1962).

There are several parts of this argument that require empirical confirmation: One is the assertion that an item is learned in a one-trial, all-or-none fashion; the other is the assertion about constant increments in error percentages. We defer the discussion of evidence for one-trial learning. Jensen includes several tests of the equal-increment prediction in his paper. Figure 5-13 reproduces one of those sets of results. The empirical order in which items are learned is used to construct the rank of scores on the abscissa. The straight line is an a priori prediction from the hypothesis and involves no arbitrary constants. The data are fit quite well by the straight-line relationship.

Jensen (1962b) has data to show that the straight-line relationship in Fig. 5-13 is relatively unaffected by certain variables that disturb the customary order in which items are learned. For example, a novel or unusual item placed in the series will be learned faster than neighboring items—a von Restorff effect. In Jensen’s view, the novel item comes to serve as another anchor point in the list, and other items are learned around it. Although the novel item modifies the
order in which items are learned, there is little benefit to learning the entire list; certain items are simply interchanged from their customary order of learning. The relative percentage errors on an item remains a linear function of its rank order of learning. Other experiments (cf. McGee and Irion, 1952) have altered the customary serial position curve by instructing the subjects to attend and work first on various subsections of the list. The anchor point in the series can be readily modified by such instructions and, hence, the serial position curve is altered. Although such results are interpretable in Jensen’s theory, Murdock’s theory of position distinctiveness would seem not to allow for this alteration of the serial position curve by different instructions to the subjects.

A second assumption of Jensen’s theory is that each serial item is learned in an all-or-nothing fashion. That is, the learning of an item is not a continuous, progressive process that grows over trials. No increment in associative strength to an item occurs until its neighboring items are learned. At the point where the neighboring items are learned, the subject begins work on learning the given item and then learns it in all-or-nothing fashion (cf. the one-element model in Fig. 5-9a). The evidence for this position is fragmentary at the moment. One supporting fact is presented in Fig. 5-14, taken from Jensen’s paper (1962a). The curve shows, for the last item learned, the percentage correct responses over trials preceding the last error on that item. The striking feature of the estimates in Fig. 5-14 is the absence of any improvement in performance prior to the trial on which the last error occurred on the item. In the task yielding the data in Fig. 5-14, the responses were known in advance so that subjects could guess correctly with a certain low percentage (28 per cent in fact). Jensen plotted backward curves for each of the nine positions in his serial list, and each of the curves resembled the graph in Fig. 5-14. Also, the chance probability of a correct response prior to learning was about the same at the nine serial positions. Thus, there was no improvement in performance at a given position until the trial of the last error at that position. The result probably would not be obtained with lists in which the items must be learned as integrated responses during the experiment. But such data are not particularly relevant to the ordering issue at hand.

The assumption of Jensen’s theory is that the associative strength of certain items in the middle of the list is not built up over all trials, but only after certain other items (at the beginning and end) are learned. Bolles (1959) has reported some evidence confirming this assumption. About one-third of the way through the course of learning a nine-item list of nonsense syllables, the subjects had the fourth and sixth items interchanged in the list. If these items had acquired associative connections to their neighboring items, then at least four connections (involving items 4 and 6 as stimulus and response terms) would now be wrong and would interfere with the subsequent course of list acquisition. On the other hand, if these middle items had developed no connections over the early trials, then the interchange should result in no interference in subsequent learning. Bolles’ result supported the later prediction. Trials to the criterion of list mastery were nearly identical for the interchange condition and for the control (noninterchange) condition. Also, the average errors made at the fourth and sixth positions (and their neighbors) were about the same for the two conditions. Bolles replicated this result in a second experiment and added a third condition in which the fourth and sixth syllables were replaced by new ones about one-third of the
way through learning. The introduction of new items at these positions at that point in learning did not retard subsequent learning of the list. In fact, the lists with replaced or interchanged items were learned slightly faster than the control list. Jensen (1963) has replicated the essentials of these results. Thus, the results support the view that associative strength of the items in the middle of the list is not acquired steadily over all trials. These results by Jensen and Bolles challenge the traditional view that serial position learning is a gradual, continuous process. Alternatively, they encourage the development of simpler all-or-none models for serial learning.

**LONG-TERM RETENTION AND FORGETTING**

The common fact of forgetting is well known. In the laboratory setting, the amount forgotten is calculated as the difference in performance on the last trial of initial learning and on a later test for recall. An alternative method measures retention by how easily the material is relearned. If material initially required ten trials to be learned and later was relearned in four trials, then a 60 per cent savings on the second test was produced by the prior learning. The question in theoretical analyses of forgetting is, how are we to conceptualize what happens during the retention interval that produces the performance decrement? The answers to this question point to two kinds of factors: change over the retention interval in the background, contextual stimuli that supported the prior performance, and changes in the strengths of competing responses to the experimental stimuli resulting from interpolated learning or spontaneous recovery of old associations established prior to the learning of the new association.

There is sufficient positive evidence concerning the decremental effect on performance of changes in contextual cues. McGeogh and Irion (1952) have reviewed research showing the supportive role for recall of seemingly irrelevant background cues. The fluctuation theory of Estes (1955) supposes that uncontrolled changes constantly occur in the contextual cues, leading to performance decrements classified as forgetting. Irion (1948, 1949) proposed that the subject's performance "set" with respect to the task changed during a retention interval. The set includes attitudes, postural adjustment, and the direction of attention. An intriguing possibility is to identify Estes' idea of fluctuating background stimuli with Irion's notion of slowly changing performance sets. Evi-
ence has accumulated (e.g., Irion, 1949; Irion and Wham, 1951; Thune, 1951) showing the beneficial effect on recall of reinstating by some “warming-up” activity the performance set lost during the retention interval. Irion’s hypotheses also explain the typically poor correlation between first-test recall scores and savings scores derived from relearning. First-trial recall is often poor, but the material is relearned quickly with considerable savings. The performance set is absent before the first recall trial, but it is reinstated during the first few trials of relearning, once the subject “gets back into the swing of things.” The research on warm-up effects is not unequivocal, however (e.g., Rockway and Duncan, 1952), and explanations for a few negative findings are lacking. The relevant literature on this topic has been reviewed by Adams (1961).

By far the most experimental work on forgetting has tested the notion of response competition (interference) as it affects retention. Postman (1962) has provided a good review of the evidence on this interference idea. McGeogh (1942) gave an early explicit statement of interference theory, and it is eminently simple and direct. If a subject has learned the stimulus-response connection A-B, then subsequent learning of the connection A-C will interfere with recall of B as a response to A. In McGeogh’s version, the interpolated learning of A-C was supposed not to alter the strength of the prior connection A-B. Response B to A became less probable simply because a strong habit had been developed to a competing response, C. The forgetting of laboratory materials was presumed to result from interpolated learning occurring with similar materials between original learning (OL) and the recall test. This theory led to explicit study of competition and forgetting in the paradigms called retroactive and proactive interference experiments. Retroactive interference (RI) refers to the decrement in recall of list A produced by interpolated learning (IL) of list B. Proactive interference (PI) refers to a decrement in recall of a reference list because of prior learning of a similar list.

Not surprisingly, the major results from interference experiments are explained easily by the competition of response theory. The recall of A-B

Fig. 5-15. Relative response frequencies of the originally learned response ($R_1$) and the newly learned response ($R_2$) during learning of the new response as measured by modified free recall. The four graphs come from four different groups of subjects given 2, 5, 10, or 20 trials of original learning. (Briggs, 1937)
increases with the amount of OL on A-B and decreases with amount of IL on A-C (cf. a review by Slamecka and Ceraso, 1960). Recall of an initial list is poorer the greater the number of similar lists interpolated before recall of the first list (Underwood, 1945). Retroactive interference increases with the similarity of the stimuli in OL and IL, being greatest when the stimuli are identical. Changes in background contextual factors between OL and IL result in less RI when recall of the first list is carried out in the same context as initial learning (Bilodeau and Schlosberg, 1951; Greenspoon and Ranyard, 1957). These results are sensible in light of the response competition theory.

Briggs has conducted some experiments which permit assessment of the relative strengths of the old and the new habits during the course of interpolated learning. Using an A-R₁, A-R₂ paradigm, Briggs (1957) trained subjects for varying numbers of trials on OL followed immediately by IL with the same stimuli but new responses. At various points during IL, modified free recall tests were given with the stimuli. On such tests the subjects were instructed to give whatever response first came to mind, and there was no feedback from the experimenter to indicate which response was wanted. The curves in Fig. 5-15 give a graphic description of the frequency of the new (R₂) and old (R₁) responses after varying numbers of OL and IL trials. At the beginning of IL, the frequency of R₁ depended directly upon the number of OL trials. During the course of IL, R₁ decreased in frequency while R₂ increased. In an earlier study, Briggs (1954) investigated the change in R₁ and R₂ frequencies over various time intervals following IL. At the end of IL, the R₂ frequency was high and R₁ low, as in Fig. 5-15. However, with the passage of time, the relative frequency of R₂ declined and that for R₁ increased; after an interval of several days, R₁ and R₂ occurred with about equal frequencies on the modified free recall test.

One implication of the competition of response theory is that the amount of RI should covary directly with the number of intrusions of responses from the interpolated lists; that is, forgetting is the result of such intrusions. However, the correlation is frequently lacking. Melton and Irwin (1940) found, for example, that although RI increased with amount of IL, the number of intrusion errors increased then decreased with larger amounts of IL. At higher degrees of IL, the subjects were simply unable to give a response when trying to recall those from the first list. Melton and Irwin suggested that first-list responses are unlearned (extinguished) during the course of IL; thus, the greater unavailability of first-list responses with higher degrees of IL is explained. The unlearning was presumed to result from the nonreinforced intrusions of first-list responses during IL. Alternatively, one might view it as counterconditioning; that is, acquisition of a new response automatically extinguishes an old response to that stimulus complex.

There is some direct evidence for this unlearning of first-list responses. The experiment by Briggs (Fig. 5-15) is not definitive since only one response was requested, and the decreasing frequency of R₁ during IL could result simply from more successful competition of R₂ responses. An experiment by Barnes and Underwood (1959) assessed the availability of both R₁ and R₂ during IL. After initial PA learning, subjects received IL with the same stimuli but different responses. On the modified recall test given immediately after the IL trials, the subject was asked to give both responses to each stimulus and to identify which response came from which list. Their subjects could frequently recall both responses and could identify accurately the list membership of

![Fig. 5-16. Mean number of responses recalled and correctly identified with stimulus and list with the A-R₁, A-R₂ paradigm. Eight is the maximum possible score in each case. (Barnes and Underwood, 1959)](image-url)
the recalled responses. Over a longer recall interval one would expect list identification of the responses to become less accurate. The results of primary interest are the recall curves of $R_1$ and $R_2$ over the course of IL. These results are shown in Fig. 5-16. As these results show, although the subject tries to recall both $R_1$ and $R_2$, the old $R_1$ responses become increasingly unavailable as IL progresses. The decline in $R_1$ is not simply due to the greater passage of time with more IL trials. A control group had OL to criterion, then rested for a time equivalent to that required for twenty IL trials; a recall test then yielded a mean recall of 7.75 $R_1$ responses, better than $R_1$ recall for the groups given any amount of IL. Thus, the $R_1$ responses seem to be unlearned or counter-conditioned during the course of IL. Adams (1961) has replicated these findings. In addition, she measured the retention of both list responses after delays of two and seven days and found evidence for the spontaneous recovery of first-list responses over time following IL.

The pattern of findings in the Briggs, Barnes and Underwood, and Adams studies may be interpreted within the stimulus fluctuation theory which the writer favors. The fluctuation theory is easily extended to take into account the period of interpolated learning of incompatible responses; the form of the extension is given only schematically here (cf. Estes, 1959). The relevant information is shown in Fig. 5-17 which represents within a pictorial model the relevant stages of conditioning of a single stimulus item in a retroactive interference experiment.

The population of stimulus events identified with successive presentations of the experimental stimulus is represented pictorially by a large circle. The division at the middle divides the population into those stimulus elements that are temporarily available ($S$) for sampling and conditioning and those elements temporarily unavailable ($S'$). For simplicity of exposition, we suppose that each stimulus element is connected either to response 1 from the first list (open dots) or to response 2 from the second list (filled dots). Performance at any time is determined by the connections of the constituent elements in the available set, $S$. At the end of original learning which is carried to a stringent criterion, the elements are connected to $R_1$. During interpolated learning, the elements in

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**Fig. 5-17.** Representation of the stimulus fluctuation model. Open dots represent stimulus elements connected to the first-list response; filled dots are elements connected to the second response learned during interpolated practice. The top figure represents the situation after a small amount of interpolated training; the bottom figure represents the situation after a larger amount of interpolated training.
the available set are counterconditioned, becoming connected to \( R_2 \). Figure 5-17 shows two cases in which learning on the interpolated list is carried out for few or for many trials, thus counterconditioning few or many elements of the temporarily available set of elements that were formerly connected to \( R_1 \). However, notice that elements that are unavailable during interpolated learning remain connected to \( R_1 \). If subjects are given modified free recall tests (Briggs, 1954) immediately after IL, then with a small degree of IL they will recall more \( R_1 \) than \( R_2 \) responses; with a high degree of IL, they will recall more \( R_2 \) than \( R_1 \) responses because the former \( R_1 \) elements in the available set have been counterconditioned to \( R_2 \).

Now imagine that a rest interval is imposed between the end of IL and a later test for modified free recall. During the rest interval, the process of stimulus fluctuation results in some interchange of elements between \( S \) and \( S' \), the amount of change in the constituency of the available set, \( S \), increasing exponentially over time. The change is such as to bring the proportions of \( R_1 \) elements in \( S \) and \( S' \) towards equilibrium; that is, the proportion of \( R_1 \) elements in \( S \) tends over time to approach the overall proportion of \( R_1 \) elements in the entire population of elements. Thus, at the delayed free recall test, the probability of \( R_2 \) will have declined because of the loss from the available set of elements connected to \( R_2 \). Similarly, the probability of \( R_1 \) will have increased because of the influx into the available set of stimulus elements connected to \( R_1 \). These \( R_1 \) elements are those that were "saved" from counterconditioning because they were unavailable during interpolated learning. Briggs' results (1954) show this exponential decline in \( R_2 \) probability and the exponential rise in \( R_1 \) probability over the temporal course of a retention interval. The forgetting of \( R_1 \) and the spontaneous recovery of \( R_1 \) both follow from Eq. I. If one is interested in \( R_1 \) probability, then we set \( p_0 = 0 \) and \( p' = 1 \) in Eq. I and \( p(t) \) describes the course of spontaneous recovery of \( R_1 \). Similarly, if we set \( p_0 = 1 \) and \( p' = 0 \) in Eq. I, then \( p(t) \) describes the course of forgetting of \( R_2 \) the response acquired in interpolated learning. The model can be extended in a simple way to handle the Barnes and Underwood (1959) data, where the subject tries to give two responses to each test stimulus.

A simple corollary of the temporal changes in \( R_1 \) and \( R_2 \) probabilities is that the relative amounts of IL and RI should change systematically over time since the end of IL. Immediately following IL, RI should be strongest and PI negligible. However, as time passes since the end of IL, RI should decline and PI increase, so that eventually there is little difference in their magnitudes. Underwood (1948) has reported results supporting this corollary.

**Forgetting without Explicit Interpolated Learning** Early estimates of the amount forgotten without explicit IL were rather large, ranging around 60 to 75 per cent forgetting of an experimental list over one day. Such results came from experimental designs which used each subject repeatedly in a variety of learning-forgetting conditions. This massive forgetting put an interference theorist in an uncomfortable position. In some way, he had to claim, a good deal of interfering learning had gone on over the twenty-four hours to account for the drastic drop in retention. The argument lacked conviction since it was difficult to see what a person learns in everyday life that could interfere with the retention of nonsense material.

This uncomfortable perplexity began to dissolve, however, when investigators began using each of their naive subjects in only a single list-forgetting condition. It is now clear that a naive subject will retain about 75 to 80 per cent of a list (of words or nonsense) over a 24-hour interval. These facts were collated by Underwood (1957), who showed that the massive forgetting resulted from the procedure of using a subject repeatedly in a variety of list-forgetting conditions. Such conditions lead to an accumulation of proactive interference. Collating the studies in the literature, Underwood showed that the percentage of material retained after twenty-four hours was a strict decreasing function of the number of prior lists learned by the subjects. The average percentage retention of a single PA list was about 75 per cent one day following learning to a criterion of one perfect recitation. Allowing for the normal post-criterion drop (to 90 per cent, say), then a retention loss of only about 15 per cent has to be accounted for. The quantity seems more within the range that could be handled by the notions of interference from casual interpolated learning and fluctuations in contextual stimulation (warm-up) between training and test.

Underwood and Postman (1960) have at-
tempted to identify and study some of the extra-
experimental sources of interference that pro-
mote forgetting of materials subjects learn in the
laboratory. They appeal to preestablished lan-
guage habits or associations which are partially
unlearned during the course of learning new ex-
perimental material. Practice and/or spontaneous
recovery of these old habits during the retention
interval is assumed to produce the retention loss.
They identify two sources of extraperceptual
habits that may enter in this way. One of these is
letter-sequence habits. Thus, the consonant-
syllable JQB violates previously established let-
ter-sequence habits since Q never follows J in natural
language but all the vowels do, and most vowels
would spell a word. Thus, during the learning of
JQB as a response unit, certain previously learned
letter-sequence habits would have to be extin-
guished. From this analysis, one would expect
high-frequency trigrams to be better remembered
(less interfered with) than low-frequency trigrams
because learning of the latter units requires break-
ning common letter-sequence habits. Their results
bear out this prediction. A second factor Under-
wood and Postman identify is unit-sequence
habits, represented by interassociations between
word units. To use their example, if the word over
has a preestablished connection to there, then the
connection would have to be unlearned in a serial
list involving over and there as nonconsecutive
items. If unlearning of the connection occurs dur-
ing initial training, spontaneous recovery of the
association will result in errors (forgetting) at re-
call. These considerations lead one to expect that
a serial list of high-frequency words, having many
associations, will be forgotten faster than a list of
high-frequency trigrams that are not words
(having few associations). Differences in this di-
rection were obtained from relearning scores
though not on the first-recall trial. These prelimi-
nary results provide an opening wedge for in-
vestigations of forgetting using materials with
various relationships to the linguistic habits of the
subjects.

A clear demonstration of sequential interference
because of language habits has been provided by
Coleman (1962). Coleman had his subjects at-
tempt to recall a sequence of twenty-five letters
they had studied briefly. The letters were scram-
bled initially; after studying them for a brief time,
the subject was handed twenty-five cards bearing
the twenty-five letters and asked to arrange them
in the original serial order he had studied. The
order reproduced by the first subject was recorded
and given to a second subject to study and then
recalled. The sequence recalled by the second sub-
ject was given to a third subject, and so on, through eleven successive subjects. As the original
sequence passed through each subject, it was re-
arranged little by little. The misorderings uniformly
shifted towards the occurrence of letter sequences
having higher frequencies in English than did the
original random sequence. In a second experi-
ment word-sequence interference was demonstrat-
ed by this successive reproduction method.
An English sentence of twenty-four words was
taken from a book, the word order scrambled,
then given to the first subject to study. He then
attempted to reconstruct the sequence of the
words he had just studied. Coleman filtered such
reproductions through sixteen successive subjects.
The results leave little doubt that successive repro-
ductions tended towards sensible English sen-
tences. The example below shows the contrast be-
 tween an original sequence and its sixteenth
reproduction.

Original
about was good-looking way and treating made
of that a him the quiet
younger nice he man-
ners a them girls wild
go with

16th Recall
he was a younger nice
quiet with manners
good-looking and a way
of treating them that
made the girls go wild
about him

(From Coleman, 1962)

One could not ask for a more direct demonstra-
tion of extraperceptual interference by language
habits with the novel habits that one attempts to
set up in the laboratory.

REINFORCEMENT IN VERBAL LEARNING

In human verbal learning, the primary effect
promoting learning is knowledge of results or in-
formation about the correct response. When the
subject is set to learn, those of his responses
followed by the experimenter’s announcement
“Right” tend to be repeated; similarly, informing
the subject of the correct response tends to in-
crease the probability of that response. Some of
the experimental material relating to these rein-
forcement operations is discussed in this section.
It will be assumed throughout that the subject is
motivated to learn the relevant materials. By this
is meant that certain manipulations have been performed, usually via instructions, which orient the subject to the task, which initiate rehearsal of the material with intent to learn, which sustain performance throughout training, and which define the adequacy of its performance. This has been called an "intentional learning set." Another class of studies of incidental learning are concerned with the effects of deleting or altering important parts of the motivating instructions. Reviews of the material on incidental learning may be found in other sources (e.g., Postman and Sassenrath, 1961; Adams, 1957; McGeogh and Irion, 1952; Postman, 1947).

Reinforcement variables typically refer to those acting at the time an S-R item receives one trial of training. Considering the anticipation method of PAL, one can identify two classes of information events that are used following the subject's response to a given stimulus. One class of events are indicative only of the congruence between the subject's response and the correct one, e.g., right or wrong. The other class of "operations" evokes the correct response, e.g., presenting the unit which the subject reads aloud. The first method of providing information is generally applicable only when the response alternatives have been restricted in advance through instructions or background conditioning. An interesting counterexample to this uniform methodology is a PA experiment by Underwood and Schulz (1960), in which the subject was reinforced for any verbal response he made to a given stimulus.

A number of studies have investigated the effects of right (R) and wrong (W) given following a subject's responses when these are selected from a known set of r alternatives (e.g., the first r integers). One is interested in the probability that the subject will repeat the response to a given stimulus on the next trial. The repetition probability of connections called R or W is compared with an empirical baseline repetition probability obtained when the connection is followed by neither R nor W (i.e., nothing, N). This latter baseline is required since frequently the repetition probability following N is greater than the chance level of 1/r. As would be expected, the probability of repeating a response to a stimulus which was followed by R is increased above the baseline repetition probability. However, evidence can be amassed (e.g., Thorndike, 1932; Buchwal, 1962) to indicate that in the usual PA situation W typically has only a small, often negligible, effect on repetition probability. The size of this effect is larger the less the number of response alternatives. Buchwald (1983) has provided a useful model which brings orderliness into an otherwise puzzling array of facts regarding the effects of R, W, and N. His model relies upon a neat distinction between the subject recalling his response (given last trial to a stimulus) and recalling the information (R, W, or N) given following his response to that stimulus. The two recall processes are assumed to be independent. Responses are learned by their contiguity to the stimulus. The main effect of information events (R, W, N), insofar as they also are recalled when the stimulus recurs, is to modify performance probabilities (of the response recalled, if any). By developing a model along these lines, Buchwald was able to predict numerically a variety of results with good accuracy.

TEMPORAL PARAMETERS IN PAIRED-ASSOCIATE LEARNING All theories of learning emphasize the necessity of temporal contiguity between the stimulus and response terms to be associated. Several experimental variables that affect learning rate in PAL can be understood in terms of the probability that one or another procedure promotes the necessary coincidence between the S and the R terms. Theories differ in whether contiguity is considered to be a sufficient basis for learning; for example, Thorndike (1932) and Hull (1943) supposed that a satiety or positive reinforcer was required in addition to the basic S-R contiguity. Such differences are immaterial in the discussion which follows; that is, we examine some variables in PAL which theoretically affect only the likelihood that S-R contiguity occurs, and this latter event is assumed uniformly to be a necessary condition for learning.

If one considers the events that occur on a single trial with a PA item, several important time intervals can be identified. The first interval of some importance is that between stimulus presentation and the occasion for the subject's response. Suppose that the stimulus term is presented briefly, then removed, and the subject is prevented from rehearsing it by some immediate interfering activity, such as counting backwards. After a brief period, he is stopped and asked to give the appropriate response that goes with the stimulus shown a few seconds before. The procedure resembles the "delayed-response" method
used for the study of immediate memory with animals. Although the study has not been done, there is little doubt that the results would be comparable to that found with animals; the longer the delay before the response is permitted, the poorer presumably will be the performance.

The presumed decrement in performance by this procedure would be ascribed to the subject forgetting the stimulus before he could respond. Since the interval affects the probability that the stimulus is available at the time for response, this interval would be considered as a factor affecting performance rather than learning. However, by a simple variant on the procedure, one may convert it into a variable affecting learning. Suppose training on the PA list is carried out by alternate study trials and no-information test trials with the stimuli alone. On study trials one may vary the time between the brief exposure of the stimulus and the presentation of the response term to be associated with that preceding stimulus. This variable is like the CS-US interval in Pavlovian studies of trace conditioning. Assume that a gain in associative strength occurs whenever the subject recalls the stimulus term at the time the response term is presented. The longer the delay interval, the less likely it is that a reinforcement (S-R coincidence) occurs. Presumably, then, learning will be slower the longer the interval separating presentation of the stimulus and the correct response term. This simple relation is yet to be tested, but it seems clear that it should be found.

A second time interval which may be examined by the anticipation method is the time between the subject's response and the presentation of information by the experimenter. Again, assume that the subject is engaged in some interpolated activity during the delay interval. The information presented by the experimenter may be of two types: one type aids rehearsal of the correct response (e.g., presenting the stimulus and correct response terms); the other does not reinstate the response (e.g., saying "right" or "wrong"). The effect of the response-to-information interval should depend on which procedure is adopted. By the latter method (saying R or W), the subject may well forget the response he gave, or the stimulus presented, or both, and in neither case will the information, R or W, be of any help to establishing the correct association. Saltzman (1951) introduced a 6-second delay by this method and found that it retarded the rate of verbal learning. Landsman and Turkewitz (1962) have reported similar results. This situation approximates closely conditions of delayed reward in animal studies. By contrast, if the stimulus and correct response term are presented together at a delay following the subject's response, there is little reason to expect that the delay would produce slower learning. The procedure ensures that each trial with a given item terminates with the stimulus and response terms in temporal coincidence; the delay between the subject's initial guess and the subsequent coincidence should be of no consequence.

A third time interval of importance in verbal learning is the duration of the simultaneous exposure of the stimulus and response terms, viz., the study time per pair. Taking an analog to animal studies, the variable may be analogous to the duration of consummatory activity used to reinforce the animal. Alternatively, it may be analogous to the number of contiguous S-R pairings per trial unit. In human learning, this study-time variable has an obvious effect on overall learning rates. Figure 5-18 below shows some results obtained by the writer, relating total errors before learning to the study time per item. Subjects learned sixteen syllable-number pairs by alternate study and test trials. On study trials, each S-R

![Fig. 5-18. Average errors per item related to the study time on the item. Unpublished results of Bower, 1960.](image-url)
pair was presented for 1, 2, 4, or 8 seconds for
different subjects; on nonreinforced test trials,
each stimulus was shown for four seconds and the
subject tried to supply the appropriate response.
The measure plotted in Fig. 5-18 is the average
errors per item per subject before a criterion of
list mastery was attained. The results in Fig. 5-18
can be accounted for theoretically. Assume that
the effect of increasing the study time is essen-
tially to provide more “subtrials” of rehearsal for a
given S-R pair. If each rehearsal has the same
strengthening effect on the association, then the
net learning rate for a study time of length $t$
will be an exponentially increasing function of $t$
(by Eqs. 2 and 3). Since total errors per item is
proportional to the reciprocal of the net learning
rate, the mean errors will be the reciprocal of an
exponential increasing function. The relation de-
scribes the data in Fig. 5-18 reasonably well.

**Variations in Degree of Reinforcement**

If we identify reinforcement with information, then
the amount of reinforcement will vary with the
specificity of the information (given to the sub-
ject) about what is the correct response. The more
specific the information, the more likely it is that
the necessary stimulus-response connection will
be rehearsed by the subject. Trowbridge and
Cason (1935) varied the specificity of feedback
information given to blindfolded subjects who
were trying to draw 3-inch lines. After each re-
sponse, some subjects were told nothing, some
were told “right” or “wrong,” and others were
told the exact amount and direction of their error.
The first group showed no improvement; the sec-
ond group slight improvement, and the third
group considerable improvement over trials in
their ability to produce a 3-inch line.

Bower (1962a) has adapted a similar proce-
dure to paired-associate learning. Suppose that
the responses are drawn from a small set of
known alternatives, such as the integers from 1 to
10, and to each stimulus the subject is to associ-
ate a particular number. Assume that when the
subject says the correct number, he is told “right.”
Several training conditions can be devised to vary
the probability that the correct response will be
reinforced following trials on which the subject
makes an error. The possible forms of information
following an error might be as follows: (a) com-
plete correction—“2 is correct,” (b) noncorrec-
tion—“wrong,” or (c) varying degrees of partial
correction—“4 or 2 or 7 is correct.” In the latter
case of partial correction, the subject is instructed
that only one of the numbers given is correct and
the other two numbers are distractors (chosen at
random), but there are no cues to distinguish the
one correct answer. Partial correction can be in
various degrees depending on the number of
“possibly correct” responses told to the subject.
These conditions form an obvious continuum, and
they can be shown to produce graded changes in
net learning rates. Learning is fastest under com-
plete correction, slowest under noncorrection, and
partial correction conditions are intermediate in
learning rate. In an experiment comparing these
conditions, Bower (1962a) showed that the re-
sults were predicted with quantitative accuracy
by assuming, first, that the effect of saying $R$
following a correct response was the same in all
conditions, viz., the probability of the correct re-
sponse following $R$ increases by the equation

$$p_{n+1} = (1 - \theta)p_n + \theta.$$  \hspace{1cm} (4)

The conditions differ in the operator applied to
$p_n$ following an error. With complete correction,
the same operator as in Eq. 4 is applied to in-
crease response probability. With partial correc-
tion, where the subject is told $k$ possibly correct
alternatives, the $\theta$ in Eq. 4 is replaced by $\theta/k$
to obtain the new response probability. With non-
correction, when “wrong” follows an error, the
identity operator is applied, i.e., $p_{n+1} = p_n$. Using
these assumptions, the results from the three train-
ing conditions were predicted accurately using a
single common estimate of the basic learning
rate, $\theta$.

The reader may note that the variables dis-
cussed under this subheading of amount of rein-
forcement have not included variations in the
amount of symbolic reward (e.g., money) pro-
vided the subject. Money or tokens symbolic of
value correspond to what most people would mean
differently amounts of reward. The obvious ques-
tion is whether learning progresses faster the
greater is the monetary payoff for correct re-
sponses and the monetary loss for errors. In the
verbal learning context, the question has been in-
vestedigated frequently and with almost uniformly
discouraging results (e.g., Thorndike and Forlano,
1933; Rock, 1935; Eisenson, 1935). Typically,
giving material incentives in addition to informa-
tion $(R, W)$ results in little, if any, increase in
learning rate; in those cases in which a small effect
of incentive conditions is obtained, the size of the effect does not increase with the size of the monetary payoff. With adult subjects, the motivation induced by the intentional-learning instructions apparently yields a rate of learning with simple information which is so high that the addition of special incentives has little influence.

One can arrange special experiments in which monetary payoffs have differential effects because they convey different amounts of information. A study by Keller, Cole, Burke, and Estes (1965) is exceptionally clear on this point. Their subjects learned a two-choice paired-associate task involving twenty-five different stimulus items. For each stimulus, there were two possible responses: one response was worth \( x \) points when chosen, the other \( y \) points, and \( x > y \). The values for \( x \) and \( y \) were the possible combinations of 1, 2, 3, 4, or 5 points over different items in the series. The points were convertible into cash at the end of the experiment. Subjects were instructed to learn to choose that response to each stimulus which had the larger value. Two conditions were run: in the first, after the subject's response, the worth of both responses was shown; in the second, the subject was informed only of the points associated with the response he chose for that stimulus. The effect of payoff on the results was different for the two groups. With complete information, the rate of learning (to choose the larger-valued response) was not affected by the values of \( x \) or \( x - y \) for an item; with incomplete information, learning rate on an item increased directly with the number of points, \( x \), for the larger alternative and with the difference in points, \( x - y \). This difference in outcomes may be interpreted in terms of the probability that the two conditions lead to identification and rehearsal of the "correct" response by the subject. This identification requires some comparison between \( x \) and \( y \). In the complete information condition \( x \) and \( y \) are shown, so identification and rehearsal of the higher alternative occurs on each trial after the subject's choice. In contrast, the comparison is difficult when the subject is informed only of the points associated with the chosen alternative. Either he must remember the points associated with the other alternative or he must make some judgment of the likelihood that the chosen alternative is the higher valued of the two. The probability of a favorable judgment (and hence reinforcement) when the correct response occurs will increase with \( x \) simply because

an overall high value is more likely to be the local higher value in a set of two alternatives. The same reasoning carries through in explaining the influence of \( x \) upon the results in the noncorrection condition.

This information analysis of the experimenter's "reinforcement operations" leads us to consider how the subject interprets the various actions the experimenter takes conditional upon his (the subject's) responses. The effect of the subject's interpretation is most readily seen when one or more of the experimenter's actions are ambiguous (Estes and Johns, 1958). One factor affecting how the subject interprets ambiguous experimenter action is the context of alternative experimenter actions in which this ambiguous one is embedded. Buchwald (1959a, 1959b, 1960) has shown that the nothing event, \( N \), following responses can be varied in its effect on learning depending on whether \( N \) is alternated with \( R \) alone, with \( W \) alone, or with both \( R \) and \( W \). The reinforcing value induced onto \( N \) (via the subject's interpretation) is opposite in sign to \( R \) or \( W \), whichever occurs alternately with \( N \). He obtained similar results with the ambiguous "mmmh" uttered by the experimenter following the subject's response.

The basic notion in these studies is that of changing the reinforcement value of a given event via its contrast with other reinforcing events occurring in the same context. There is supportive evidence for this notion from experiments on differential rewards with animals (Bower, 1961b; Crespi, 1942; Black, Adamson, and Bevan, 1961; Reynolds, 1962). Bevan and Adamson (1960) have stated the hypothesis concisely and have related it to Helson's theory of adaptation level which explains certain phenomena of psychophysical judgments (Helson, 1959). This theory supposes that a subject judges the apparent sensory magnitude of a stimulus by referring it to an internal norm or standard (the adaptation level or AL). Furthermore, the internal norm is derived, via an averaging process, from the background and the stimulus events that have occurred over the immediate past of the subject. Thus, the apparent or judged loudness of a 70-db tone will be lower when it occurs within a series of 90-db tones than within a series of 50-db tones. Applying this notion to a continuum of reinforcing stimuli (e.g., electric shocks), the apparent magnitude and, hence, reinforcing effect of a given intensity reinforcing stimulus will vary according to
the alternative reinforcing stimuli occurring in the same context (which determine the AL).

Bevan and Adamson (1960) have conducted some preliminary experimental tests of this idea. In one of their experiments, the task for the subject was to learn to move a hand stylus through a 28-unit bolted maze. At each of the twenty-eight choice points, there were two boltheads, one left and one right, and the subject made his choice by touching one of these with the stylus. If he touched the wrong one, he was given a brief shock of 2.3 ma, then corrected himself and went on to the next unit of the maze. The shock of 2.3 ma is the negative reinforcing stimulus in the study. Bevan and Adamson attempted to manipulate its value as a reinforcer by giving a prior series of 30 shocks of either 1.3, 2.3, or 3.3 ma to different groups of subjects. The prior shock series is presumed to establish an appropriate adaptation level, and hence should affect the apparent intensity of the 2.3 ma shock given during the subsequent maze training. For subjects adapted with 1.3 ma shocks, the maze shock of 2.3 ma would appear to be very strong, and hence they should quickly learn to eliminate errors. Conversely, subjects adapted with 3.3 ma shocks would perceive the 2.3 ma shock as relatively weak and should learn more slowly. Each subject was run five trials on the 28-unit maze, and the rate of reduction in errors over trials confirmed the predictions. Subjects adapted with 1.3 ma shocks learned fastest and those adapted with 3.3 ma shocks learned slowest.

This AL conception of magnitude of reinforcement seems a fruitful one and efforts should be made to extend it to other kinds of reinforcers with human subjects. Before the idea can be fairly tested with other reinforcement continua, it first would be necessary to show that AL-type effects occur when the subject makes psychophysical (category) judgments along the prospective continuum. The size of these contextual effects will probably depend on the type of continuum, whether physical (shock) or symbolic (approval), and the extent to which category judgments along the continuum have been overlearned in the subject's social environment.

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