A COMPARISON OF FORWARD AND BACKWARD CHAINING TECHNIQUES FOR THE TEACHING OF VERBAL SEQUENTIAL TASKS

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FOREWORD

These studies represent a portion of the applied research program of the Technical Training Branch, Training Research Division, Behavioral Sciences Laboratory of the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. The studies were conducted under Contract AF 33(615)-1046 with the University of Cincinnati, in support of Project 1710, "Training, Personnel and Psychological Stress Aspects of Bioastronautics," Task 171007, "Automated Training and Programed Instruction." Dr. G. A. Eckstrand was Project Scientist; Dr. R. L. Morgan, Task Scientist; and Dr. K. A. Johnson, Technical Monitor for the Aerospace Medical Research Laboratories. Dr. R. J. Senter was Principal Investigator for the University of Cincinnati.

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ABSTRACT

Three experiments were conducted to determine the relative merits of forward and backward chaining in the learning of sequential (serial) tasks. Previous research with animals has indicated the superiority of backward chaining and this principle frequently has been proposed for human learning. In all experiments the materials consisted of lists formed from familiar items (numbers, letters, words) arranged in arbitrary sequences. In the forward-chaining technique the subject begins by practicing the first item in the sequence. Next he practices the first and second items, then the first, second and third items, and so on until he is practicing the entire sequence. In the backward-chaining technique the subject begins by practicing the last item in the sequence. He then practices the next-to-the-last and last items, then the third-from-last, next-to-last, and last items, and so on until he is practicing the entire sequence.

In all three experiments, the forward-chaining technique was superior to the backward-chaining technique. In the first experiment, this difference was not reliable, but in each of the remaining experiments, it was.

SECTION I

GENERAL DISCUSSION

There is an obvious need for a technology of training that will aid the instructor in arranging materials to facilitate the learning of sequential or procedural tasks. Most of the experimental work in this area has been devoted to investigations of the relative merits of whole-task and part-task learning. The consensus of several reviews of this material (Deese, 1952; Underwood, 1964) is that although there is much interaction with such factors as amount of previous practice, intelligence, and type of task, in the majority of cases the whole method has proved to be at least as good as the part method.

Recently there has been a renewed interest in a particular form of cumulative part-task learning. The student begins by practicing the terminal elements of a sequential task. When these are mastered, new elements are added at the beginning of the practiced portion, and the student works on this expanded sequence. On successive trials, additional elements are added to the beginning of the sequence until the student is practicing the entire sequence of behaviors. Thus, a student who wished to learn a sequence consisting of elements ABCD would begin by practicing D, then CD, BCD, and, finally, ABCD. This backward-chaining technique is one of the most salient features of Mathetics, a system that has been developed as a guide to the writing of programed instruction (Gilbert, 1962).

This backward chaining of responses is an extension to human education of a procedure widely used in the training of lower animals. Specific advantages it offers for the training of animals include those associated with problems of efficient reinforcement. In certain sequences the reinforcing event (e.g., the delivery of a food pellet) is not particularly portable, that is, cannot be conveniently moved from one to another location within the chain of responses. In such circumstances one must insure that each chain terminated with the reinforcing event delivered in its natural location. A second, more general, problem is that previously mastered behaviors will be extinguished each time a new element is added to the chain.

Consider the behavioral chain of a pigeon which has been trained to make an "observing" response. The pigeon begins by noting that the key over the food cup is not illuminated (S_1^D). He then steps on a pedal (R_1) which illuminates the key. If the illumination is red (S_2^D), the pigeon pecks the key (R_2) which activates a food delivery mechanism that produces a distinctive click (S_3^D). Upon hearing this, the bird approaches the food cup (R_3) and consumes the food. The R's represent responses by the bird and the S^D's serve two functions in such a chain: first, they play their normal role as discriminative stimuli, i.e., they establish the occasions on which the responses that follow them in the chain will be rewarded; second, they serve as conditioned reinforcers for the responses that precede them in the chain.

Now consider the procedures that might be used in developing such a behavioral chain. Assume that the trainer begins by bringing the first response, stepping on the pedal, under the control of the first discriminative stimulus, nonillumination of the key, by reinforcing the bird with food on each occasion that R_1 is emitted in the presence of S_1^D. Now he would like to add the response R_2 to the sequence and bring it under the control of S_2^D. He might attempt to do this by withholding the food until the bird performs both R_1 in the presence of S_1^D and R_2 in the presence of S_2^D. Under such circumstances the pigeon will probably emit a large number of R_1's which are not followed by R_2's. Since these R_1's will not be reinforced, the bird may well be extinguished on R_1 before the link between R_1 and R_2 can be developed.

Such difficulties might be avoided if the trainer proceeded in the opposite direction. Assuming that he has already taught the pigeon to peck the red key to obtain food (S_2^D through R_3) and wishes to add the pedal stepping response (R_1) to the beginning of the chain, he could make the red illumination of the key (S_2^D) contingent upon R_1. The pecking response (R_2) to the red key (S_2^D) will not extinguish, since the key will be red only after R_1 has been emitted; thus, the chain will be permitted to run its course; i.e., the S_2^D - R_2 sequence will continue to be reinforced. Also, S_2^D will provide the conditioned reinforcer for R_1. The trainer might also control the occurrence of S_2^D by using it as a conditioned reinforcer to shape the pigeon's behavior to the stepping response. Again, the chain from S_2^D to the consumatory response would be permitted to run its course.

If you wished to teach the average airman to perform a task similar to the foregoing, you would simply tell him to perform the sequence, and might even mention that he would receive an appropriate reward, e.g., a quarter, upon the successful completion of the task. Although one would not suggest that the airman be trained in the same way as the pigeon, the comparison brings out some of the features which distinguish the two situations. Although the quarter does not play a necessary role in the airman's learning of the sequence, it may serve to increase the likelihood that he will repeat the sequence without being told to do so. There are many sequential tasks, however, for which a high rate of spontaneous responding is not particularly desirable, e.g., reciting the alphabet, doing long division, or firing an ICBM. Since reinforcement of some kind is necessary if the airman is to learn the sequence, that reinforcement is apparently provided somewhere between the instructions and the airman himself.

Most learning theorists believe that variations in amount of reward effect performance rather than learning (Deese, 1952; Kimble, 1961). The experimental evidence indicates that an increase in amount of reward, above the minimum level that may be necessary for learning, will probably increase the speed or vigor with which a response is made, but that such an increase will have little or no effect on the organism's ability to make the response. Since our hypothetical airman can derive sufficient reinforcement for learning from the instructions alone, the additional reward of a quarter or the completion of a meaningful task should have little effect on his actual learning of the sequence.

Extinction is possible during the learning of longer sequences. It will be helpful, however, to consider alternative interpretations of the term extinction. The term is relatively unambiguous in the case of classical conditioning, but in the case of complex, instrumental behaviors there are problems. If one withholds the terminal reinforcement, does one reduce the animal's ability to perform the complex response, or merely his inclination to do so? These terms may seem mentalistic, but the experimental separation of the two possibilities is fairly straightforward, even in animals. In the case of humans, one must labor to ignore the distinction. At this level, withholding the terminal reinforcement reduces (albeit in a highly inefficient manner) the subject's inclination to emit the behavior in question. In our previous example, if we had withheld both the quarter and our approval, the airman would eventually have stopped performing the sequence. However, if we tell him that the game has changed and that he will again obtain the quarters, there is little doubt that he will promptly demonstrate his ability to perform the sequence. In fact, the airman will probably have overlearned the sequence itself during the period of extinction.

One would not expect a human student to encounter the same difficulties as the pigeon in learning a task of the type the pigeon encountered. It is only on tasks so difficult that the student cannot grasp and retain all of the required steps on the basis of a single description or demonstration that one would run the danger of extinction while attempting to learn additional material. Even here, the danger is more apparent than real. As noted previously, the effective reinforcement in many tasks of this type is furnished by the student himself. A student who has learned to activate a bombing-navigational set will probably continue to reinforce himself for the successful completion of this sub-sequence during the period in which he is learning the additional steps required for the complete checkout procedure. In distinction from the animal situation, the instructor might even continue to provide reinforcement for the activation subtask during the learning of additional steps.

The basic differences between the human and animal situations are in the techniques that can be used for transmitting information from trainer to trainee. When new elements are added to a sequential task, the behaviors that were previously both necessary and sufficient for obtaining a desired state of affairs are still necessary but are no longer sufficient. The animal trainer who attempts to add the new elements to the end of a sequential task has no means to signal this change other than by withholding the reinforcement, and this is a highly ambiguous signal. Until the animal has emitted the new chain of behaviors at least once, it has no means by which it can discriminate between changes that have rendered its previous behaviors insufficient and changes that have rendered its previous behaviors both insufficient and unnecessary. The extinction of the previously correct behaviors could be viewed as a highly probable form of misunderstanding. However, the animal trainer who adds new elements to the beginning of a sequential task can solve his communication problem before the new elements are introduced. Once the previously correct behaviors have been brought under the control of an S^D, the change in sufficiency can be brought about by manipulations of the task itself, i.e., the occurrence of the S^D can be made contingent upon the animal's emitting the new elements. The animal has neither the need nor the opportunity to test the altered sufficiency of the previously correct behaviors. With human students the teacher can simply state that the previously learned responses are still necessary, but that the student must now add certain new behaviors. Such instructions are not dependent on whether the new elements are added to the beginning or end of the task.

The exact nature of the new behaviors represents a second block of information that must be transmitted from the trainer to the trainee. The animal trainer who adds the new elements to the end of the task will generally be forced to rely on the animal's ability to stumble upon the new behaviors through trial and error, but the animal trainer who adds the new elements to the beginning of the task can use his control of the S^D to shape the animal to the new behaviors. With human students, as long as the responses of the new behaviors are in the student's repertoire, and as long as the segment falls within the student's assimilation span, the teacher need only describe or demonstrate the required behavior. Again, it makes no difference whether the new behaviors are added to the beginning or end of the previously correct sequence. In summary: the backward-chaining technique represents a highly efficient method for communicating with non-verbal organisms, but a rather inefficient technique for communicating with verbal organisms.

The man who has done most to popularize the backward-chaining technique has recently pointed out that the changes in rate of responding produced by verbal instructions do not necessarily resemble the changes produced by direct manipulation of the reinforcing events (Skinner, 1963). This lack of correspondence might indicate the problem faced when attempting to generalize in the other direction, i.e., from behaviors formed through direct manipulations of reinforcements to behaviors formed by means of verbal instructions. The problem is even greater when one attempts to generalize from data on rate of responding to the acquisition of new sequences.

Even though the generalizations from animal experiments to human learning of the type covered herein are not compelling, the backward-chaining technique might prove effective for other reasons. One such reason has been offered by Gilbert (1962). He suggests that when a task is taught by means of the successive "fading"[1] of elements, the more difficult elements should be faded first. There are several reasons why such a procedure might prove effective, the most obvious of which is that the greatest amount of active practice is devoted to those elements that most need it. Since in most serial tasks the greatest difficulty is experienced with elements in the latter half of the sequence,[2] backward chaining, which provides more practice on items late in the sequence, might prove more effective than either forward chaining, which provides more practice on items early in the sequence, or the conventional whole-task techniques, which distribute practice evenly over the entire sequence.

Slack (1964) has reported several experiments that bear on the preceding conjectures. Using meaningful verbal sequences and a fading technique, he found that the early fading of difficult elements did indeed lead to more efficient learning than did the early fading of easy elements. He also conducted two comparisons between forward and backward chaining using similar materials and techniques. In the first experiment he found that backward chaining was significantly better than forward chaining, but some doubts might be raised about the extent to which the two versions of the task were matched on factors other than the direction of chaining. In a second, more adequately controlled, experiment he found that the backward technique was once again better than the forward technique, but this time the difference did not reach the conventional levels of statistical significance.

There might be some question about the extent to which the fading technique provides a true case of backward chaining, even though the technique was used in several of Gilbert's original examples (Gilbert, 1962). When a student is presented a sequence of the type ABC_, he has an opportunity to learn the subsequence ABC. This learning will probably be of the conventional forward-chaining type, since this is the way in which one normally reads a sequence of this sort. The blank space tests whether or not on previous trials the subject learned the subsequence CD, but, unless

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[1] With the fading technique, the experimenter first presents the entire sequence, then on each successive presentation deletes certain of the elements. If the student does not remember the deleted elements, he is given the correct answer by the experimenter. The "frames" for a backward chain might run as follows: ABCD, ABC_, AB_ _, A_ _ _; those for a forward chain might run as follows: ABCD, _BCD, _ _CD, _ _ _D, _ _ _ _.

[2] Maximum difficulty is generally experienced at a point slightly past the middle of the sequence.

he fails to produce the required response and is prompted by the experimenter, it does not represent the point at which the original learning of CD takes place.[1] Slack's data suggest that most of the learning took place during the reading of the sequences rather than during the test trials on which prompts were supplied by the experimenter. On the other hand, items faded early in the sequence were more likely to be correct on the criterion trial than were items faded late in the sequence.

The experiments reported herein were designed to provide additional evidence on the relative merits of the forward- and backward-chaining techniques. They differ in two respects from the procedures suggested by Gilbert (1962) and employed by Slack (1964) in his experiments. First, they employ an accretion rather than a fading technique of presentation. The task begins with the presentation of a single element; then on each successive trial one new element is added to the sequence. This technique is probably not as efficient as the fading technique, at least for human subjects, but it does represent a closer approximation to the chaining technique used with animals. The second difference is in the materials themselves. In the following experiments the elements are not organized into sequences that are meaningful to the naive subject. The primary reason for the use of such materials was that they would provide better control over context effects, a type of control which is difficult for such materials as conventional prose or poetry. Many of the sequential tasks faced outside the laboratory are of exactly this same meaningless type, e.g., checking out a bombing-navigational set or learning the alphabet.

SECTION II

EXPERIMENT I

PROCEDURE

Twenty-four college students were randomly divided into two groups of 12 students each. For each subject, two lists of common 3-letter nouns were constructed by sampling, without replacement, from a population of 100 such nouns. Each subject was presented one list under instructions for forward chaining and one list under instructions for backward chaining. The two groups differed only in terms of whether they learned the first list by means of forward or backward chaining.

Under forward chaining, the subject was told that he would be read a list of 3-letter nouns. After the first noun, he was simply to repeat the noun. After the second noun, he was to repeat both the first and second nouns in that order; after the third noun, he was to repeat the first, second, and third nouns, and so on until he made an error in repeating the entire list. The instructions for backward chaining differed only in that he was instructed to recite the nouns in an order opposite to that in which they were presented; i.e., after the second noun, he was to repeat the second and first nouns, in that order; and after the third noun, he was to repeat the third, second, and first nouns, in that order. Subjects were permitted to take as much time as they wished in repeating the lists.

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[1] Learning does take place on test trials, but this learning is generally less efficient than that which takes place on simple presentation trials of the "ABC" type (Angell and Terry, 1962; Kaess and Zeaman, 1960).

RESULTS

For each technique, the subject received a score equal to the length of the list which he successfully repeated under that technique prior to his first error. The mean length for the forward chaining technique was 5.42; for the backward chaining technique 4.83. This difference was not statistically significant ($.10 < p < .20$).

The data indicated that all subjects successfully repeated at least two items under each condition. This indicates that the instructions were sufficient to insure that all subjects understood the tasks. On the other hand, several subjects failed on lists of length three. The low averages obtained by the subjects indicate that they were operating under considerable cognitive strain. Part of this was probably due to negative transfer between both lists and techniques, although the drop from an average of 5.46 items on the first list to 4.79 items on the second list failed to reach the 0.05 level of significance. The F ratio for the confounded between groups and treatment by order interaction effects was less than 1.

SECTION III

EXPERIMENT II

The second experiment was designed in an effort to reduce the components of variance stemming from both cognitive strain and inter-subject differences in the difficulty of lists. It also provides a further sampling of both materials and presentation techniques.

PROCEDURE

Twenty-four college students were randomly divided into four groups of six students each. Each student was trained on two lists, one under a forward-chaining technique and the other under a backward-chaining technique. One list consisted of 11 numbers drawn from the range between 1 and 20; the other, of 12 consonants. Each list was constructed so as to avoid successive items with obvious associations, e.g., T-V or 3-4. The same basic sequences were used for all subjects. The beginning of the list, however, was randomly determined for each subject. The four groups provided a counterbalancing for the order of lists and presentation techniques.

Procedures under the forward- and backward-chaining techniques were quite similar. The experimenter read a list at the rate of about one item per second. The subject was required to repeat the list as he had heard it. Under the backward-chaining technique, the experimenter began with the last item in the list. Each time the subject repeated the list successfully, another item was added to the front of the list, e.g., V, ZV, MZV, etc. When the subject made a mistake, the list was repeated. The list remained unchanged until the subject recited it correctly. The forward-chaining technique differed only in that the experimenter started with the first item in the list and added successive items to the end of the list, e.g., M, MZ, MZV, etc. Subjects were allowed as much time as they wished for their responses. They were run until they had made two successive correct repetitions of the complete list.

RESULTS

For each technique, the subject received a score equal to the number of trials he required to reach criterion. The mean number of trials required under the forward-chaining technique was 20.54, under the backward-chaining technique, 24.83. The probability of such a difference occurring by chance is less than .01. The second list proved easier than the first ($p < .01$), indicating that the changes in instructions and techniques were sufficient to eliminate the negative transfer found in the first study. In spite of a pilot study designed to equate the number and letter lists in difficulty, the letters required more trials ($p < .01$). None of the interactions reached the .05 level of significance.

SECTION IV

EXPERIMENT III

The final study was designed to provide a comparison of the two types of chaining when they are used in conjunction with an anticipation-confirmation type of serial presentation. It also provides a comparison between these techniques and the more traditional whole-task method of serial learning.

PROCEDURE

For convenience, three classes of college students were assigned as units to the three treatments. Each class was run as a single group. Although the groups appeared similar in terms of such characteristics as age and sex, an index of rote learning ability was used as a control variable to prevent potential differences among the classes from interacting with the effects of the treatments. This index consisted of the subject's score on a matching test over 12 paired nonsense syllables which he had studied for 5 minutes. This index correlated significantly with performance in the main experiment (correlations between .33 and .40 in each of the three groups, each significant beyond the .05 level). It was, therefore, used in an effort to reduce the variance within groups. The three groups did not differ significantly ($F < 1$) on this index.

Each group learned the same list of 15 consonants by means of a modified anticipation technique (anticipations were covert rather than overt). Individual consonants were projected on a screen at the front of the classroom. Each stimulus was displayed for 1 second; the interstimulus interval was 0.5 seconds.

Subjects in the Conventional group were told that they would receive repeated presentations of the entire list, and that on each trial they were to anticipate, covertly, the consonant which would appear next. Eight trials, for a total of 120 stimulus presentations, were given under this condition.

Subjects in the Forward group were told that they would begin with the presentation of a single consonant (the first in the list) and that on each successive trial one additional consonant would be added to the end of the list until the list contained a total of 15 consonants. They, too, were told that they were to anticipate, covertly, the consonant which would appear next. This procedure required a total of 120 stimulus presentations, the same number as was employed for the Conventional group.

Subjects in the Backward group were told that they would begin with a single consonant (the last in the list) and that on each successive trial an additional consonant would be added at the beginning of the list. The remaining instructions were identical to those used for the Forward group. This procedure also required a total of 120 stimulus presentations. Note that the final trials were exactly the same for all groups, i.e., a sequential presentation of the complete 15-item list in exactly the same order.

Next, all groups were tested by having the subjects reproduce the entire list, in order, from memory (T_1). The list was written on a piece of paper. There was a minimum of time stress. Following this first test, all subjects were given one trial under the Conventional condition, then tested again (T_2). This was followed by another trial under the Conventional condition, and a third test (T_3).

Three weeks after the learning session, the subjects were asked to reproduce the list from memory a fourth, and final, time (T_4).

RESULTS

To facilitate statistical analysis, all groups were matched in terms of size. This was done by discarding randomly selected subjects from the two largest groups until all groups contained 43 subjects.[1]

The 15-item list was broken down into 15 ordered pairs. The first of these consisted of the starting point (SP) and the first consonant (SP, 1); the second, of the first consonant and the second consonant (1, 2); the third of the second consonant and the third consonant (2, 3); and so on to the end of the list. An error was scored for each ordered pair omitted from the subject's list. For example, a subject who omitted the first consonant from his list, i.e., SP, 2, 3, _, 15, would score two errors, since neither SP, 1 nor 1, 2 appears in his list.

The mean number of errors per group over the first three test trials is presented in figure 1. An analysis of covariance on these data (using the rote learning test scores as a control variable) indicates that the effect of test trials was significant ($p < .01$), but that the effect of treatments was not.[2] There was, however, a significant ($p < .05$) interaction between treatments and test trials. An examination of figure 1 indicates that this interaction stems from the convergence of groups over test trials. This is not surprising, since all groups following T_1 received additional learning trials in the same (Conventional) mode. Also, by the time the groups reached T_3, a number of subjects were making perfect scores.

Since there are substantial a priori grounds for assuming that T_1 would be most sensitive to the experimental effects, a separate analysis of covariance was performed on this test alone. This time a significant ($p < .01$) difference was found between the treatments. Table I presents the means and adjusted means for the three groups.

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[1] The comparison on the control variable cited previously and all other analyses, unless noted otherwise, were conducted with 43 subjects per group.

[2] An analysis of variance on the unadjusted data also failed to indicate significant differences for the treatment effect.

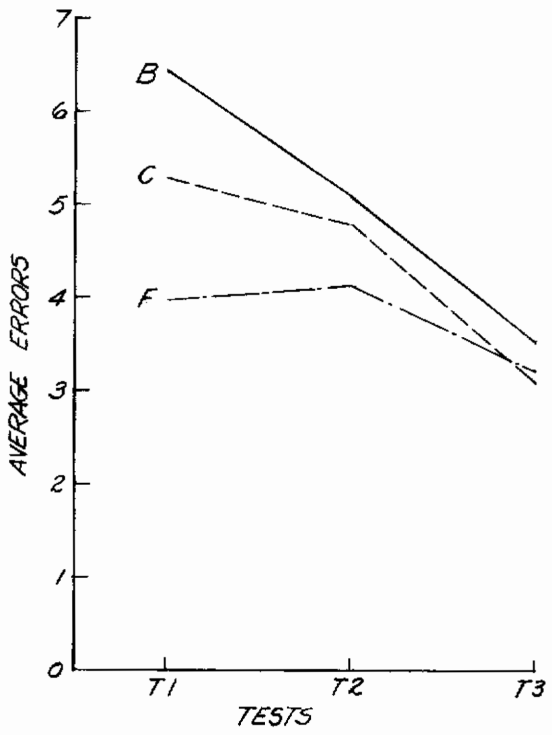

Figure 1. Unadjusted Mean Number of Errors Per Group Over the First Three Test Trials.

TABLE I

AVERAGE NUMBER OF ERRORS ON TEST TRIAL T_1

	Treatments		
	Backward	Conventional	Forward
Means	6.42	5.30	3.98
Adjusted Means	6.39	5.50	3.81

The Duncans Multiple Range Test indicates that on T_1 the unadjusted means of the Forward and Backward group differ significantly ($p < .01$, error term based on the simple analysis of variance). When applied to the adjusted means, it indicates that the Forward group differs significantly from both the Conventional and Backward groups ($p < .05$ and $p < .01$, respectively, error term based on the simple analysis of covariance).

The average number of errors per ordered pair during T_1, calculated over blocks of three pairs, is shown in figure 2.[1] These curves are much as one might have expected them to be. The Conventional group has a conventional serial position curve. The Backward and Forward groups also show traces of such a curve (the maximum number of errors occurs in one of the middle blocks). In each case, however, the effects of different amounts of practice on the various blocks are apparent. These curves indicate that the differential effects of treatments extend over major portions of the serial list; the overall differences found for T_1 cannot be attributed entirely to a few items at the beginning or end of the list.

The data from T_4 (the retention trial) indicate almost complete forgetting of the task (at least in terms of ordered recall). The Backward group averaged 12.37 errors; the Conventional group, 12.34 errors; and the Forward group, 11.82 errors.[2] Although the general pattern of these means is similar to that found at the completion of original learning, the differences were far short of the conventional levels of statistical significance.

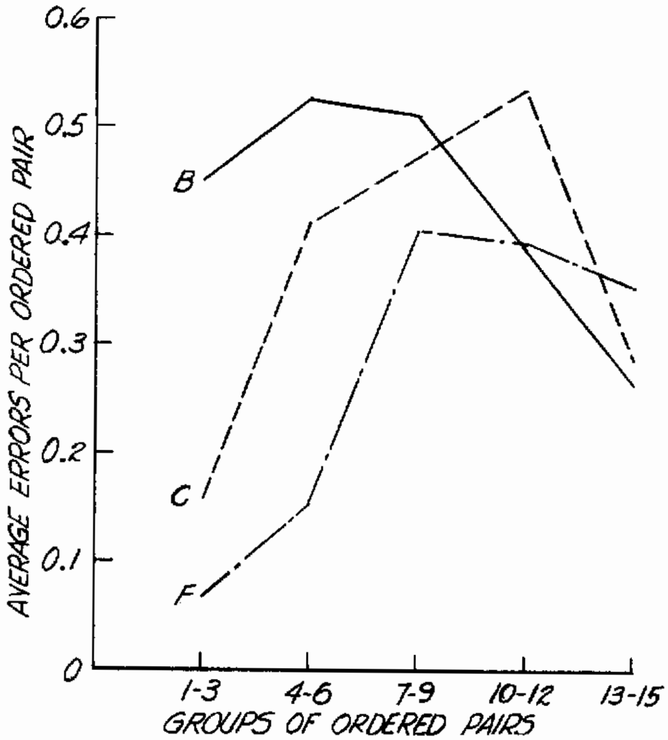

Figure 2. Unadjusted Mean Number of Errors Per Ordered Pair During T_1, Calculated Over Blocks of Three Pairs.

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[1] These data were computed over all subjects. The N for the Backward group was 43; for the Conventional group, 51; and for the Forward group, 68.

[2] Each of these means is based on an N of 38. Group size was equated in a manner similar to that used for the original learning scores. N is reduced because certain of the subjects present for the initial learning session were not present for the recall session.

SECTION V

CONCLUSIONS

In each of the three experiments, the backward-chaining technique was found to be inferior to the forward-chaining technique. In the first experiment, the difference was not reliable, but in each of the last two experiments, it was.

Since these data are at variance with those reported by Slack (1964), the differences between the techniques used in the two sets of experiments merit a closer examination. First, there is the possibility that the obtained results stem from factors that have been confounded with direction of chaining. In the experiment in which Slack found a significant difference between the two techniques, for example, the two groups also differed in terms of the amount of material they received on each frame.

Another possibility, even when the backward and forward techniques are strict mirror images of one another, is that the context provided by one procedure will differ systematically from the context provided by the other. Although differences in context are inherent in this type of experiment, the danger of these differences producing a strong systematic bias is most likely in the case of meaningful materials that are faded in something other than a strict ordinal sequence.[1]

There is also the possibility for any fixed set of materials that materials at the beginning of the list will differ in difficulty from those at the end of the list. If so, the direction of chaining would be confused with the early and late fading of difficult items, a variable which Slack has found to be of considerable importance. This latter danger exists in both of Slack's experiments and in the third experiment of the present series, though probably to a lesser degree. Such factors might have contributed to the obtained results, or they might have had no effect. Even if there were a contribution, there is no easy way to judge the direction of influence.

If one accepts the data as they stand, then one is faced by an interaction between type of materials and/or presentation techniques and direction of chaining. First, there is the possibility of an interaction between the sequential redundancy of materials and the direction of chaining. That is, backward chaining may be superior for high redundancy material, such as the poetry and prose used by Slack, whereas forward chaining may be superior for low redundancy material, such as was used in the experiments reported herein.

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[1] In the chaining of meaningful materials, it has been customary to fade elements in something other than a strict ordinal sequence. An effort is generally made to preserve a context for each of the faded elements under the assumption that such a context will serve as a cue to the correct response. In the case of a poem, for example, one might begin by deleting four words from the last line and three words from the next-to-the-last line, rather than seven words from the last line. If the various elements in such menaingful material differ in the extent to which they provide context or are dependent upon the context provided by other elements, a mirror-image-type reversal would begin by fading exactly those elements that are most useful in providing cues or prompts for the remaining elements.

A second possibility is that there is an interaction between presentation techniques and the direction of chaining. Backward chaining may be superior for materials presented by means of the fading technique, whereas forward chaining may be superior for materials presented by means of the accretion technique. In considering the possibility of such interaction, one should remember the reservation expressed earlier about the extent to which the fading technique provides a pure case of backward chaining. It may be that pure forward chaining is always superior to pure backward chaining for materials of the type used in these experiments. Subjects learning under the backward-fading technique may simply use a blend of procedures that is superior to the blend used by subjects learning under the forward-fading technique.

The interactions suggested above appear, on the surface, to be incompatible with the extrapolation from animal data. Animal chains are generally low in sequential redundancy and are traditionally developed by means of the accretion technique rather than the fading technique. In these respects they are more similar to the experiments in the present series than to those reported by Slack. It might be argued, however, that with humans the high sequential redundancy and/or fading technique serve to increase the amount of reward experienced in completing a given task, that a reward of this type is similar to the more extrinsic reward provided in the training of animals, that an increase in the magnitude of such extrinsic rewards will lead to more efficient learning, and, therefore, that backward chaining should be most efficient under these conditions.

Such an argument leads to two additional problems, one practical and one theoretical. At the practical level it will be necessary to determine which condition or conditions are essential for the superiority of backward chaining——fading, redundancy, or both. There are a number of practical learning situations in which the sequential reduncancy is low. If high redundancy is necessary for backward chaining to be more efficient than forward chaining, such tasks should be taught by means of forward chaining.

The theoretical problem is more complex. That an increase in the amount of reward will facilitate learning is a generalization developed from studies in which variations in learning were measured by variations in the rate at which a given response was emitted. The extension of this generalization to other learning situations has been tested before. In a number of cases the predictions based on the generalizations were not confirmed; in others, they were. From a purely theoretical point of view, the confirmations are somewhat irrelevant; the disconfirmations indicate that the simple generalization referred to above, by itself, is not valid when extended to learning behavior in general. Under these circumstances, the extension of the generalization to the learning of sequential tasks such as those under consideration here cannot be viewed as the application of a commonly accepted principle. It cannot even be viewed as a test or extension of the theory, since there is already ample evidence that the theory in this simple form is inadequate when applied to behavior that, under the terms of the theory, is indistinguishable from the behavior under consideration here.

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13. ABSTRACT

Three experiments were conducted to determine the relative merits of forward and backward chaining in the learning of sequential (serial) tasks. Previous research with animals has indicated the superiority of backward chaining and this principle frequently has been proposed for human learning. In all experiments the materials consisted of lists formed from familiar items (numbers, letters, words) arranged in arbitrary sequences. In the forward-chaining technique the subject begins by practicing the first item in the sequence. Next he practices the first and second items, then the first, second and third items, and so on until he is practicing the entire sequence. In the backward-chaining technique the subject begins by practicing the last item in the sequence. He then practices the next-to-the-last and last items, then the third-from-last, next-to-last, and last items, and so on until he is practicing the entire sequence. In all three experiments, the forward-chaining technique was superior to the backward-chaining technique. In the first experiment, this difference was not reliable, but in each of the remaining experiments, it was.

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