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SEVERAL METHODS FOR TEACHING SERIAL POSITION SEQUENCES TO MONKEYS[1]

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Three keys were available for monkeys to press. The objective was to teach the animals to press the keys in sequences up to 10 members in length. With fading procedures, a light that cued the correct key at a given serial member of the sequence faded out slightly each time the animal selected it, and became slightly brighter after the animal made an error at that sequence member. The correct keys were faded out, starting from the end of the sequence and proceeding toward the beginning. With control procedures, the cue lights were turned off suddenly, rather than being faded gradually. In almost every instance, the animals learned a longer series of unlighted key positions with the fading procedures than they did when each key-light was turned off suddenly. Also, requiring the animals to press a series of keys cued by lights before they could reach the sequence members they were to learn hampered them in learning the later serial members. By using several different sequences, it was possible to replicate these findings within the individual animal.

Serial position sequences have several useful features for studying learning: first, the experimenter can introduce quantifiable levels of difficulty by lengthening the sequence to be learned. The sequence can also be lengthened in a programmed, stepwise fashion until the subject can proceed no further. It is then possible to evaluate the longest sequence a subject can learn under a given set of conditions, and to investigate relevant variables while the subject is functioning at or near its limit.

Second, once a subject has learned a particular sequence of stimulus positions, it can then be taught new sequences. This permits studies of the learning process to be replicated in an individual subject; or one can follow progressive changes in the learning process in an individual as a function of such variables as lesions of the central nervous system, teaching methods, drugs, *etc.*

Third, the explicit correlation of reinforcement with stimulus position eliminates an otherwise inevitable source of uncontrolled stimulation. "Irrelevant" position cues must be at least transiently correlated with the relevant stimulus dimensions, even if the experimenter varies the placement of stimuli. The literature is replete with instances in which stimulus position enters adventitiously into reinforcement contingencies and hinders or even prevents the subject from learning a discrimination (*e.g.*, Harlow, 1959; Spence, 1936). With stimulus position as a relevant dimension, the learner can make use of this ubiquitous cue instead of being confused by it.

The major objective of the present study was to devise a method for teaching monkeys serial position sequences of a sufficient length to bring them close to their limits of performance, and to do so as rapidly as possible. The basic experimental situation was adapted from earlier work by Boren (1963).

METHOD

Subjects and Deprivation Procedures

Two male rhesus monkeys, which weighed approximately 3.8 kg when obtained from a commercial supplier, had lived in individual cages in the laboratory colony for 19 months when the experiments began. Over a period of several weeks, the animals' food intake was limited until their weight fell to 80% of the free-feeding weight. They were maintained throughout the experiments at the 80% level except for an increase of 0.01 kg at the beginning of each new month. If their weight

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was below the 80% level at the end of an experimental session, they were given enough food in their home cages to make up the difference. Their diet during the experimental period consisted solely of 1-g Ciba banana pellets,[2] supplemented by water and vitamin drops in their home cages. Experimental sessions were separated by at least one day.

Apparatus

The chamber of the sound-resistant experimental space in which the animals worked was approximately 2 by 2 by 2 ft. They were transported to the chamber in a carrying cage; sliding doors permitted the animal to leave the cage and enter the chamber at the start of each session or to go in the other direction when the session was over. The floor of the chamber was constructed of expanded metal, coated with heavy vinyl plastic. A heavy outer door sealed the chamber after the animal had entered, and a wide-angle lens in this door permitted observation of the animal.

An aluminum wall separated the animal's working chamber from the rest of the experimental space. Response keys, stimulus lamps, pellet dispenser, and control equipment were located on the other side of this wall from the animal, and another heavy outer door gave the experimenters independent access to the equipment. "White" noise in the experimental space helped to mask extraneous sounds during the experimental sessions.

On the aluminum dividing wall were three translucent circular keys which the animal could press. The diameter of each key was 0.75 in.; they were aligned horizontally, 5 in. apart and 12.25 in. above the animal's floor. Behind each key were two blue 7.5-w Christmas-tree bulbs. The brightness of the lights was controlled by potentiometers driven by stepping motors (Powerstat, with Slo-Syn drive).

A small tray, 7.6 in. below the center key, received the 1-g banana pellets that were dispensed to the animal as reinforcers. General illumination came from a Sylvania 60-w "Lumiline" bulb shining through a grill on the dividing wall just below the ceiling. Sequencing of correct keys, control of the key-light intensity, delivery of pellets, and recording of stimuli and responses were accomplished automatically by solid-state circuitry. An Esterline-Angus operations recorder provided a temporal record of the animal's key-pressing behavior in relation to the scheduled sequences of correct key positions and key illumination.

Preliminary Training Procedures

Magazine training and the shaping of key-pressing were accomplished in the conventional manner. Then, when the monkey pressed a lighted key, the light behind that key went off and another one of the three keys was immediately lighted. The animal was given a pellet each time it pressed the one illuminated key.

When the animal had learned to "follow" the lighted key, a chain of serial presses on the three keys was gradually built up, with a pellet coming only when the sequence was completed without error. At first, the animal received a pellet after pressing two lighted keys in succession; then after three presses, four, *etc.*, until the sequence reached 10 in length. For example, if the three keys are designated A, B, and C from the animal's left to right, respectively, the following sequence of 10 presses might be scheduled to produce a pellet: BABCBCACAB. The experimenter could vary the sequence at will.

If the animal pressed a dark key, the house and key lights went off for a 5-sec period of "time out". If the animal pressed a key during this period, the time out was lengthened, so that a new trial could not begin until the animal had not pressed a key for 5 sec. Throughout the experiments, the animal produced the time-out period whenever it pressed any incorrect key. If the animal pressed two keys simultaneously, this counted as an error, even if one was correct. The time-out period always ended with a return to the first member of the sequence; the animal had to begin the sequence anew after each error. This recycling procedure was used in all phases of the experiments.

The reinforcement schedule for correct completions of the sequence was then built up gradually to a variable ratio averaging one pellet per four completions. At the end of all correct trials (completions of the chain in the proper sequence) the house and key lights

[2]We are indebted to Dom V. Finocchio and Ciba Pharmaceutical Products, Incorporated, for providing the pellets.

were extinguished for 0.25 sec, whether a pellet was delivered or not. The variable-ratio schedule postponed satiation and thereby permitted the animal to have more trials per session. The purpose of the 0.25-sec time-out was to indicate the end of the sequence to the animal, even if no pellet was delivered.

Monkey R4 began the experimental procedures immediately after it completed preliminary training. Monkey R2 had additional experience with several sequences and methods of training before it entered this experiment. All of this additional experience involved variations of Procedures A and B (see below).

Experimental Procedures

Five basic sequences were used (four with 10 members and one with nine), and four different procedures were used to teach the animals the sequences. The order in which the animals learned the sequences with each teaching procedure appears in Table 1.

Table 1

Sessions numbered consecutively to indicate the order in which the animals were exposed to each procedure and each sequence.

	Constant-Length Sequence		*Lengthening Sequence*	
	Fading A	*Sudden-Off B*	*Fading C*	*Sudden-Off D*
MONKEY R2				
1. BABCBCACAB	1	2	9	10
2. BACACBCBAB	3	4	11	12
3. BCBACABACB	5	6	13	14
4. BCACABACB	7	8		
5. BACACBABCB			15	16
MONKEY R4				
1. BABCBCACAB			1	2
2. BACACBCBAB			4	3
3. BCBACABACB	6	5		

All procedures began with lights cuing the correct keys for the animals. The goal was to teach the animals to press the keys in correct sequence even after the key-lights had been removed. In two procedures, the key-lights were gradually faded out; in the other two procedures, the lights were turned off suddenly. The programs for fading and removing the lights suddenly are described below.

The brightness of the key lights can be specified in terms of three possible states: A. *Fully bright.* The lights were powered directly from the 120-v house supply, bypassing the potentiometers; B. *Objectively off.* All power to the lights, both from the house line and the potentiometers, was interrupted; C. *Fading.* The lights were powered directly from the stepping-motor-driven potentiometers. Limit switches set the highest voltage the potentiometers could deliver at 80 v, and the lowest at 9 v. At 80 v the lights were dimmer than in the "fully bright" condition but clearly visible. At the two lowest voltages the experimenters could not discern the key lights, but an operational distinction is maintained between "fully faded" and "objectively off". The stepping motors could set the potentiometers at any one of 14 voltage levels, or fading steps, including the two extreme values.

Procedure A: constant-length sequence; fade from end. If the pellet (or the 0.25-sec extinction of the house light) is considered as the termination of the sequence, the serial members of the sequence may be represented by reference to the termination. The last member becomes −1 (minus one); the next-to-last member is −2; and so on toward the beginning.

Figure 1 schematically illustrates Procedure A. The lights cuing the correct keys were faded out, starting from the end of the sequence and proceeding toward the beginning. In each session the animal first had to complete the scheduled sequence 10 consecutive times, with the correct key in each member fully bright (preliminary phase). The final member (−1) of the series was then placed in the "fading" state, at the highest fading step (phase 1). Each time the animal completed the series, the brightness of the correct key in the last member was faded so as to be one step dimmer on the next trial. Each time the animal made an error on the final member of the sequence, the light on the correct key faded back two steps toward bright for the next trial. When the correct key at −1 had become fully faded, the monkey's first nine responses on each trial were cued by key lights, but all three keys were dark when it reached the final member of the sequence.

Fading was then started at −2 (Phase 2). Whenever the animal passed −2 successfully, the key-light at that member became one step dimmer on the next trial. If it pressed a wrong key at −2, the correct key at that member became two steps brighter on the next trial.

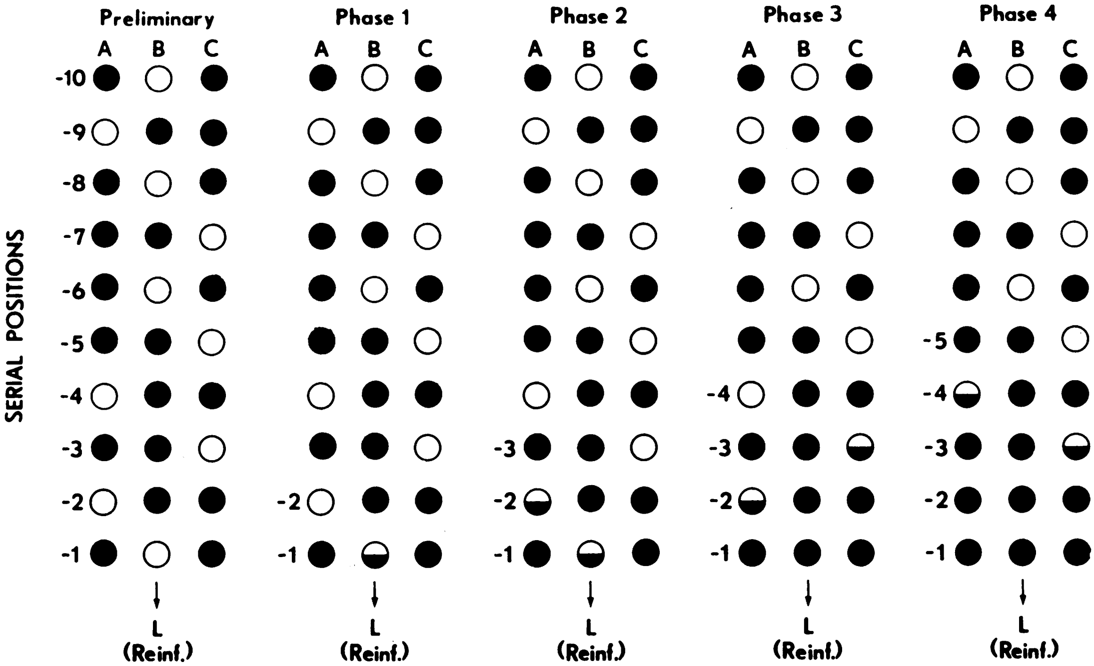

Fig. 1. Schematic illustration of the fading procedure with the constant-length sequence. The three keys are A, B, and C. Solid circles represent objectively-dark keys; open circles, fully-bright keys; and semisolid circles, keys in the fading state. In the preliminary phase, the animal had to press each of the bright keys in the sequence, BABCBCACAB, in order to reach the end. The phases of turning off keys at positions near the end and fading keys nearer to the beginning of the sequence continued until the animal met the criteria for ending the session. See text for details.

The key at −1 remained in the fading state, so that any errors the animal made on that member while −2 was fading caused the final key to become brighter.

Throughout the fading procedures, an error at any sequence member that was in the fading state caused only that member to become brighter on the next trial. Errors or correct responses at one sequence member had no effect on the intensity of the key-light at any other sequence member.

When the correct keys at −2 and −1 had both become fully faded, the monkey's first eight responses on each trial were cued by key-lights, but all keys were dark when it reached the final two members of the sequence.

The correct key at −1 was then disconnected from any voltage source and became "objectively off", remaining so for the rest of the session. Fading was then begun at −3, the correct key at −2 being left to fade back if the monkey made errors at that point in the sequence (Phase 3).

When the lights at −3 and −2 had both faded out, the correct key at −2 was turned objectively off, and fading began at −4 (Phase 4). In this manner, the correct keys were faded successively, starting from the end and moving toward the beginning of the sequence, so long as learning took place. To avoid repetition, only four phases are illustrated in Fig. 1.

Except for Phase 1, the correct keys in two serially adjacent members of the sequence were always in the fading state; when the two became fully faded simultaneously, the second of the pair was turned objectively off and the next member toward the beginning of the series was placed in the fading state. Neither animal learned all members of any scheduled sequence. A session ended when the animal failed to fade out a given key within 60 min, or failed to complete a correct trial within 30 min, whichever happened first. The same criteria for ending the session were applied in all procedures.

Procedure B: constant-length sequence; sudden-off. Instead of being faded out, successive key-lights were turned off suddenly. The recording apparatus (but not the control apparatus) behaved as if fading were taking place, subtracting one "step" for each correct response at the critical sequence member and adding two "steps" for each error at that point. In this way it was possible to use the same criteria for turning successive lights objectively off as were used to initiate fading in Procedure A. Figure 1 would illustrate the process if the semi-solid, or fading keys, were black. Whenever Procedure A specified that a key-light be placed in the fading state, Procedure B specified that it be turned objectively off. This "sudden-off" procedure, used here as a control for the fading technique, might be expected to have considerable teaching value in its own right.

Procedure C: lengthening sequence; fade from end. Figure 2 schematically illustrates Procedure C. Only the last three members of the total sequence were presented initially to the animal (preliminary phase). Fading of the last two members proceeded as in Procedure A (Phases 1 and 2). When the final two members were fully faded, a new member, −4, was added at the beginning. The new member was fully bright; −3 and −2 were in the fading state; and the correct key at −1 was turned objectively off (Phase 3). When the correct keys at −2 and −3 became fully faded at the same time, the process was repeated: A new member, −5, was added to the beginning of the sequence; the next-to-last member was turned objectively off; and fading began at −4 (Phase 4).

Procedure D: lengthening sequence; sudden-off. This was identical to Procedure C, except that the key-lights in each member of the sequence were turned off suddenly instead of being faded out gradually. The recording apparatus functioned as if fading were taking place, so that the same criteria could be used for turning the lights objectively off as were used to initiate fading in Procedure C. Figure 2 would illustrate the process if the semi-solid keys were black.

Treatment of Subjects

Table 1 shows the sequences, procedures, and the order in which the animals were exposed to each.

Monkey R2. Each session of Procedure A was followed two days later by Procedure B, applied to the same sequence. This gave the sudden-off procedure the benefit of any practice effect and biased the results against our expectation that fading would prove more effective. Then, in like succession, Procedures C and D were applied to the indicated sequences. Sequence 4 had only nine members.

Monkey R4. This animal was exposed to three sequences, the order of presentation of each procedure differing from that used with Monkey R2.

RESULTS

Fading vs. *sudden-off procedures. Constant-length sequence.* Figure 3 illustrates several aspects of Monkey R2's performance on Procedures A and B, with Sequence #1. The ordinate values in Fig. 3 derive from the procedural specification that the animal start anew at the beginning of the sequence each time it pressed a wrong key. Because of this recycling

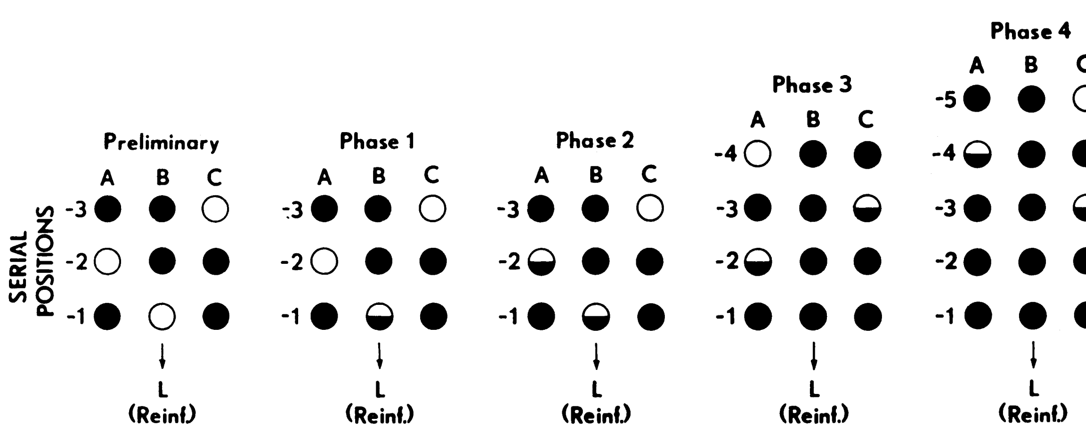

Fig. 2. Schematic illustration of the fading procedure with the lengthening sequence. See Fig. 1 and text for details.

procedure, the number of times the animal could reach a given serial member of the sequence depended on the number of errors it made at earlier members. For example, the animal reached member −3 nineteen times in Phase 1 of the fading procedure and pressed the correct key on 17 of those occasions; therefore, it had only 17 opportunities at −2. Figure 3 takes account of the declining number of opportunities the animal had to respond at later members of the sequence and indicates the number of correct responses per opportunity at each serial member during each phase.

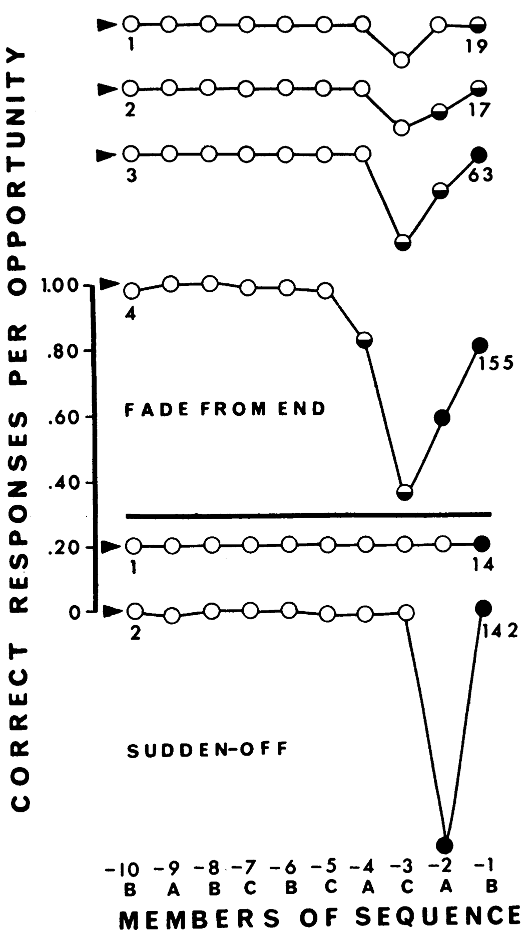

Fig. 3. Correct responses per opportunity in each phase. Monkey R2, Sequence 1, constant-length sequence. The procedures are indicated by the labels of each section. The number at the left of each curve indicates the Phase (see Fig. 1 and 2), and the number at the right tells the total number of trials in each Phase. Open, semisolid, and solid circles represent fully bright, fading, and objectively off keys, respectively. Arrows locate the ordinate value of 1.00 for each curve.

With the constant-length sequence procedure the animal started every trial at −10, the beginning of the sequence. The session ended when the animal failed to progress beyond a given point as successively earlier key lights were faded or turned off.

In Phase 1 of the fading procedure, the animal darkened the correct key of member −1 in 19 trials. It made no errors on the final member while the key light at −1 was being faded out. Completing the second phase required 17 trials (at the end, the correct keys of members −1 and −2 were fully faded). The animal was correct on 93% of its opportunities at −2, indicating that the fading of −2 caused little trouble. There were no errors at −1 while the correct key at −2 was being faded.

Phase 3 was complete after 63 trials. At the beginning of Phase 3, the light at −1 had been turned objectively off; −2 remained in the fading state, so that an error at that point made it slightly brighter; and fading began at −3. The monkey responded correctly on 73% of its opportunities at −3 and on 89% at −2, indicating that the fading of −3 caused the animal some difficulty. Again, every time the animal reached the final member of the sequence, it selected the correct key. In spite of the errors, the animal passed through Phase 3 successfully, as the existence of a curve for Phase 4 indicates. The light at −1 had been turned objectively off, and the animal had faded out the lights at −2 and −3. It can be said to have learned a sequence of three dark-key positions.

Since Phase 4 is the final one represented, it was here that the animal met the criterion for ending the session. At the start of Phase 4, the lights at members −1 and −2 were objectively off; −3 remained in the fading state, so that it became brighter each time the animal made an error at −3; and fading was begun at −4. The animal had relatively little difficulty with −4; it was correct on 83% of its opportunities and, in fact, faded the key light at −4 all the way out. But at the same time, it began to make many errors at −3, which it previously had succeeded in fading out. During Phase 4, the animal chose correctly on only 36% of its opportunities at −3, and never succeeded in getting members −4 and −3 fully faded at the same time, even after 155 trials. (The number of trials is not cumulative from phase to phase.) Errors also began to occur more frequently at −2 and −1, which had been turned objectively off and could not be faded back to a higher brightness level. It should be noted that the number of trials in the last phase of a session can be misleading, for the animal could meet the time criterion by not pressing any key for 30 min.

In the sudden-off procedure, the light at member −1 had been turned off suddenly, and at the end of 14 trials the recorder indicated that the light would have been off if it had been faded. Therefore Phase 1 lasted for 14 trials and Phase 2 started with the key-light at −2 being turned off suddenly. After 142 trials of Phase 2, the animal met the criterion for ending the session; it had not made enough correct responses at position −2 to have fully faded the key at that position. In contrast, with the fading procedure the animal had succeeded in darkening the final three members after a total of 99 trials (Phases 1-3).

Two aspects of these data were found consistently for all sequences and both fading procedures, whether the constant-length or lengthening sequence procedure was used (see below). First, as the number of dark members increased beyond two, the largest number of errors per opportunity occurred at earlier serial positions rather than later ones. Second, the end point was usually reached when the animal lost its ability to select a key it had already learned, rather than being unable to learn a new position. For example, in Fig. 3, the animal learned member −4 but lost its previously adequate performance at −3.

Fading vs. *sudden-off procedure. Lengthening sequence.* With the constant-length sequence procedure, the animal started every trial at the beginning of the 10-member sequence. Early serial members were cued by lights on the correct keys; at the later serial members, the light was either faded or turned off suddenly. However, with the lengthening-sequence procedure, the animal started with a sequence of only three, and new members were added to the beginning only after the animal had learned the later members (Fig. 2). Figure 4 shows an example of Monkey R2's performance on the lengthening-sequence procedure. Again, the animal was able to proceed further when the key-lights were faded than when they were turned off suddenly.

The terminal member of the sequence caused no difficulty, either in Phase 1 or later; differences between the fading and sudden-off procedures became more apparent as additional keys were darkened. In the sudden-off procedure, the animal made many errors when the correct key at −2 was darkened (Phase 2). It passed beyond −2 on only 35% of its opportunities, but finally did learn the last two members. When the correct key at position −3 was turned off (Phase 3), the monkey pressed the correct key at that point on only 2% of its opportunities, and rarely succeeded in reaching the end of the sequence.

In the fading procedure, the animal succeeded in darkening the keys at −1 and −2 simultaneously after 38 trials in Phase 2. Phase 3 was difficult for the animal; with the correct key light at −1 objectively off, it took 114 trials to bring −2 and −3 simultaneously to the fully-faded state. Once this was accomplished, however, it faded out the correct keys at −4 and −5 with little difficulty (Phases 4 and 5). During Phases 4 and 5, the animal

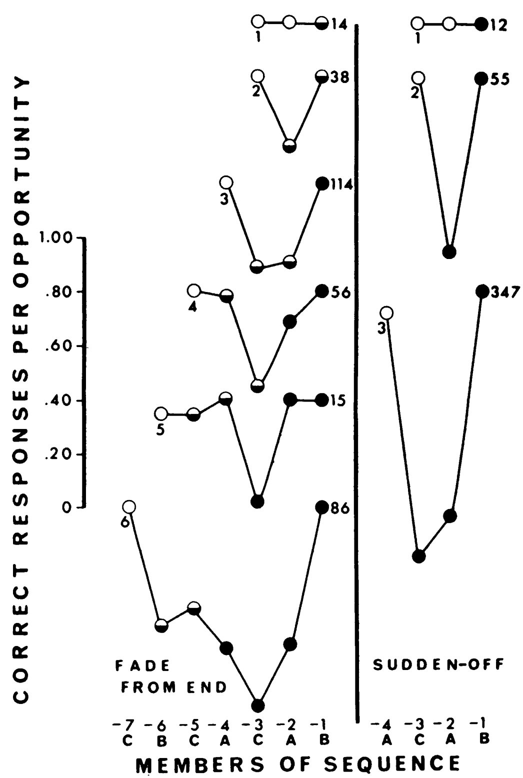

Fig. 4. Same as Fig. 3, lengthening sequence. On each curve, the ratio, correct responses per opportunity, has a value of 1.00 at the final sequence member (−1).

made most of its errors at member −3, rarely pressing wrong keys earlier or later in the sequence. In the process of fading −6, the animal's performance beyond this position deteriorated, and it did not succeed in learning more sequence members.

Constant-length sequence vs. *lengthening sequence. Fade from end.* The "fade from end" sections of Fig. 3 and 4 show examples of performances on the two fading procedures. The constant-length procedure was somewhat more efficient during the first three phases, but thereafter, the lengthening sequence carried the animal further. At the start of Phase 4, the correct keys at −1 and −2 had been turned objectively off; the animal had faded −3 fully out; and the correct key at −4 had been placed in the fading state. With both procedures, the animal had little difficulty fading out the key at −4; the key at −3, which had already faded out, produced the most errors. With the constant-length sequence, the animal went beyond −3 on only 36% of its opportunities during Phase 4, and after 145 trials it met the criterion for ending the session. With the lengthening sequence, the animal succeeded in fading out −4 and −3 simultaneously in 56 trials, and then rapidly learned an additional member in Phase 5 before reaching its limit in Phase 6.

Constant sequence vs. *lengthening sequence. Sudden-off.* The lengthening-sequence procedure proved slightly superior as a teaching technique even when the key-lights were turned off suddenly. A comparison of the "sudden-off" sections of Fig. 3 and 4 shows that the animal was unable to pass beyond Phase 2 in 142 trials with the constant-length sequence. With the lengthening sequence, the animal learned the correct keys at −1 and −2 in 55 trials of Phase 2, and then its performance deteriorated completely when the third key was turned off.

Number of positions learned. The animal was often able to learn a newly fading key at an early serial member of the sequence even though it made a large number of errors later in the sequence. Because of this phenomenon, the number of keys the animal was able to fade out does not adequately describe the number of sequence members it was able to learn or retain with each procedure.

A criterion was therefore adopted for stating whether the animal had learned or retained the correct key at a particular sequence member. Since there were three keys from which to choose at each sequence member, the number of correct responses per opportunity might be expected to equal 0.33 if the animal responded at a chance level. However, the same correct key was never repeated at adjacent serial positions. If the animal were to learn this feature of the sequences, the chance level of responses per opportunity at any sequence member would then be 0.50. This was the criterion selected. If, at the end of a given phase, the animal had responded correctly on more than 50% of its opportunities at a given sequence position, it was considered to have learned or retained the correct key at that position. The arbitrary level of 50% is relatively stringent, for the animals often did press a key twice in succession.

This criterion of learning or retention was applied only to positions at which the correct key had been turned objectively off; keys in the fading state were not considered to have been learned unless they had become fully faded.

Figure 5 shows the number of sequence members Monkey R2 learned and retained as a function of cumulated trials for each sequence and each procedure. Data points are recorded at the end of each phase of the animal's progression through the teaching process, as the keys at successively earlier serial members were faded or turned off. The letters A, B, C, and D identify the four procedures in the same way as Table 1.

Curves A and B within each sequence show the relative effectiveness of the fading (A) and sudden-off (B) procedures with the constant-length sequence. In three of the four sequences in which this comparison was made, the animal learned more sequence members by means of the fading procedure; only Sequence 3 shows no difference, and here the animal was able to learn only one key with each procedure.

It will be noted that curve A for Sequence 2 turns downward; after 200 trials the animal had learned the correct keys at the final four members of the sequence, but after 278 trials, it had learned only three members. In Phase 5, the animal succeeded in fully fading −5, but in the process of doing this, made enough errors to bring the key at member −4 back up from its fully faded state. It also made errors

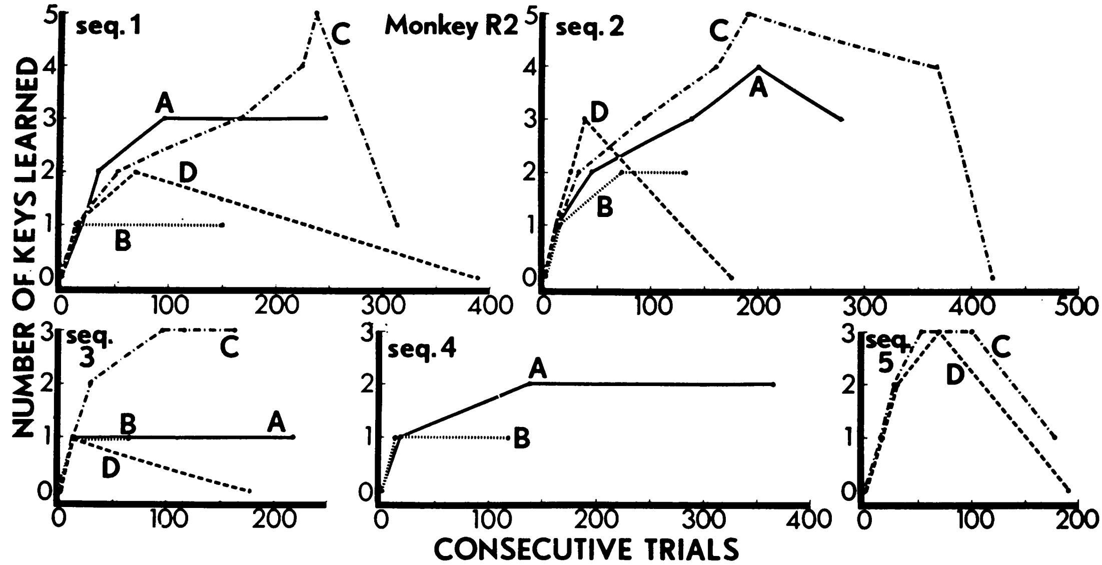

Fig. 5. The number of sequence members Monkey R2 learned and retained as a function of consecutive trials for each procedure and each sequence. The letters identifying the procedures are the same as in Table 1.

on more than 50% of its opportunities at −2. Therefore, when the session ended after 278 trials, the animal had learned the newly fading key at position −5, but had lost the previously learned keys at −4 and −2, leaving a total of three members learned. Similar failures of the animal to retain previously learned keys are responsible for all instances in which the curves of Fig. 5 turn downward.

With the lengthening sequences, the animal also learned more correct keys by means of the fading than the sudden-off procedure (compare curves C and D within each sequence). The only exception was Sequence 5, in which the animal was able to learn the correct key at three members with each procedure.

By comparing curves A with C, and B with D (Sequences 1, 2, and 3), the relative effectiveness of the lengthening and constant-length procedures can be seen. The animal learned more correct keys with the lengthening-sequence procedure, particularly when the key-lights were faded. Only with the sudden-off procedures of Sequence 3 (curves B and D) did the animal reach the same maximum sequence length by means of the constant and lengthening procedures, and in both instances it was able to learn only one position.

Unpublished data indicate that an animal's performance may improve if the same sequence is used in consecutive sessions, but that no such facilitation occurs if other sequences are interposed. Therefore, it is not likely that positive transfer from the earlier constant-length procedures (see Table 1) can explain the greater effectiveness of the lengthening-sequence procedures. Any positive transfer that did occur would only have increased the seeming effectiveness of the sudden-off procedure for each sequence.

Monkey R4 was used simply to compare the fading and sudden-off procedures with an animal that did not have Monkey R2's history. Figure 6 summarizes the number of serial members Monkey R4 learned as a function of consecutive trials with each sequence. The data of the two animals are similar, the major exception being Monkey R4's superior performance with the fading procedures of Sequence 3 (curve A). Even here, comparison of Fig. 5 and 6 shows that both monkeys required approximately 200 trials on Phase 2, but Monkey R2 met the time criterion for ending the session before it was able to complete the fading at −2. No comparison was made between constant and lengthening sequences, but within each of these procedures fading was superior to turning off the key lights suddenly.

DISCUSSION

The greater effectiveness of the fading technique confirms and extends Terrace's (1963) finding that fading can facilitate the transfer of a learned discrimination. In the present experiment, monkeys first learned a brightness discrimination. The procedures involved simultaneous, rather than successive, discriminations, since one lighted key and two dark keys were always simultaneously available to the animal. Each time the animal pressed a lighted key, the cue light shifted to another of the three keys. Because the key lights were programmed according to a fixed sequence, the cues of serial position and brightness were superimposed. This corresponds to Terrace's superimposition of lines on colors. With the fading procedure, the brightness cue was gradually removed, leaving only serial position as a guide for the animals. With the sudden-off procedure, the brightness cue was removed abruptly, also leaving serial position available to the animals. As in Terrace's experiment, fading facilitated the transfer from one stimulus aspect to another, although fading did not produce errorless transfer from brightness to serial position.

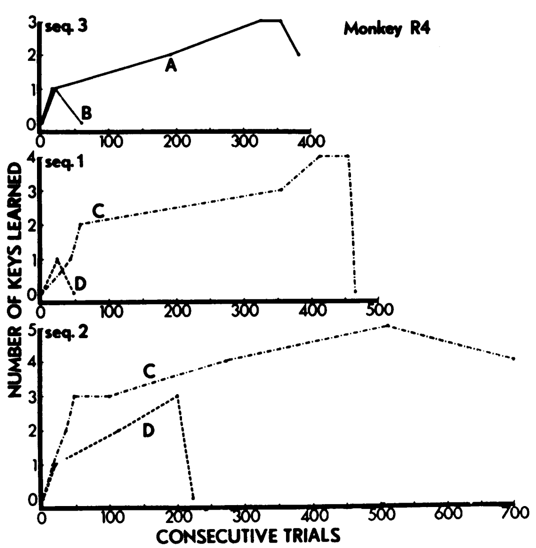

Fig. 6. Same as Fig. 5, for Monkey R4.

Terrace's (1963) experiment also demonstrated that superimposition of a new stimulus dimension (line tilt) and abrupt removal of an old controlling dimension (color), while not as effective as fading in transferring stimulus control, was nonetheless more effective than simple substitution of lines for colors. This finding is consistent with Thorndike's Law of Associative Shifting, which states that by adding new elements to a compound stimulus and then removing the old elements, we may, subject to ". . . certain limitations due to the necessity of getting an element of a situation attended to . . . get any response of which a learner is capable associated with any situation to which he is sensitive" (Thorndike, 1913, p. 15). The present experiment also shows that associative shifting can accomplish a transfer of stimulus control, and that fading facilitates the shift.

Does Thorndike's qualification, "the necessity of getting an element of a situation attended to," provide a clue to the efficacy of fading? Does fading increase the likelihood that a learner will attend to a new dimension of a compound stimulus? If so, why does fading not always succeed in so directing its attention? In the present experiment, fading was generally more effective than simple superimposition, but it did not guarantee a greater degree of transfer from brightness to serial position. Similarly, another method of fading (Sidman and Stoddard, 1967, and unpublished data) in which a new stimulus was gradually introduced (faded in) while an old one was being removed (faded out), proved more effective than trial-and-error, but not universally so.

There is, in fact, no known method for guaranteeing that a particular member of a compound stimulus will acquire control over some specified behavior. Reinforcement in the presence of the stimulus is necessary but not sufficient (*e.g.*, Klüver, 1933; Ray, 1967; Reynolds, 1961). Procedures which facilitate associative shifting may encourage such control, and fading may encourage it even more effectively, but the final step can still not be specified.

The superiority of the lengthening sequence procedure over the constant-length sequence procedure provides another puzzling phenomenon of stimulus control. Requiring the animal to press a series of lighted keys before it could reach the sequence members that were off or fading hampered it in learning the later serial members. Could the early members of the sequence have been getting in the way of the later members? The animal did not have to attend to the positions of the earlier correct keys, for they were cued by lights. But perhaps serial position exerted control anyway, consistent with its status as a member of a stimulus compound, and in conformity with the Law of Associative Shifting. In that case, however, one would expect the law to have helped the animal when the positions to be learned were extended back toward the beginning of the sequence. The constant-length sequence procedure should have been the more effective, for it gave the animal considerably more experience with the superimposed cues of brightness and serial position than did the lengthening sequence.

A second possibility is that the constant-length sequences imposed too long a time period between the animal's successive exposures to sequence members it was being required to learn. The animal had to press a series of lighted keys before reaching later members of the sequence, and perhaps it could not retain the correct positions of the later keys during that time interval. Unpublished experiments indicate that monkeys retain four-member sequences for a considerably longer time than they take to complete 10-member sequences, but that they quickly forget five-member sequences. The lesser effectiveness of the constant-sequence procedure may be related to this interaction between sequence length and retention interval.

A third aspect of the data is the great variability among the different sequences with respect to the number of members the animals learned. Sequences 3 and 4, which shared the final six members in common, were the most difficult. The most successful procedure—fading, with the lengthening sequence—was considerably more effective with Sequences 1 and 2 than with Sequences 3 and 5. Also, within each sequence, certain members were more difficult for the animal to learn and/or retain than others. Although detailed analyses of the animals' errors at each position were made, the fact that only three keys were available to the animals made it impossible to separate out anticipatory errors, repetition errors, and errors that might have been produced by idiosyncracies of pair or triplet frequencies within each sequence. A technique which gave the animals more than three keys from which to choose would permit a finer analysis of error sources, and would permit relevant comparisons with the large literature on serial rote learning.

A fourth observation was that the animals tended to fade out new sequence members relatively easily while making many errors at serial members that they had previously learned. During some phases they made so many errors on previously learned keys that they rarely or never reached the end of the sequence; at the same time, they rapidly learned new members early in the sequence.

An extreme example, although we have seen several like it, appears in Fig. 7. This animal, which was exposed to Procedure C but did not participate in the formal experiment, succeeded in turning off the key-lights at all 10 members of the series. But, in Phase 6, the animal failed to get past −1 to the end of the sequence. In Phase 7, although the correct responses per opportunity equaled 1.00 at −2 and −1, the animal actually completed the sequence only once. From Phase 8 through 11, the animal never reached the end of the series. Nevertheless, with only one reinforcement (in Phase 7), the animal faded out the correct keys at five new sequence members (−6 to −10) with relative ease in the 211 trials from Phase 6 through Phase 11.

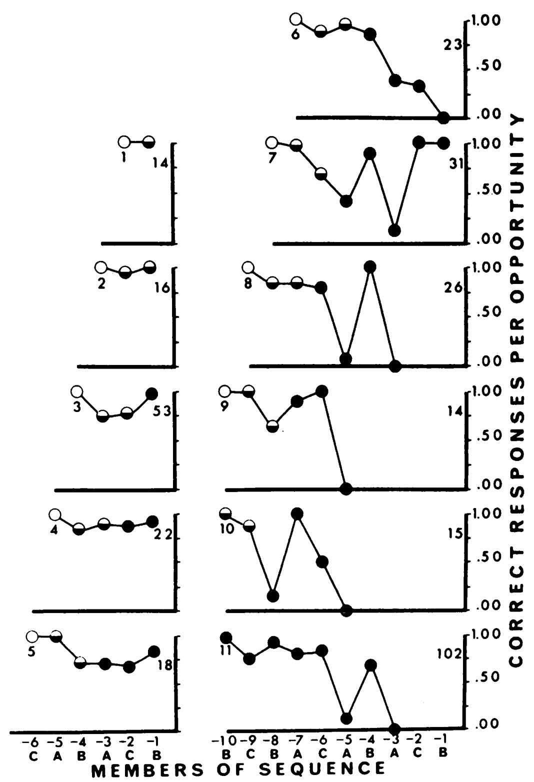

Fig. 7. Correct responses per opportunity in each phase. Monkey R8, lengthening sequence, fade from end. The number at the left of each curve indicates the phase; the number at the right gives the total number of trials in each phase.

If the sequence is regarded as a form of fixed-ratio schedule, with a pellet coming only after the animal completes a fixed number of correct responses, the learning of early members of the series even without a pellet illustrates the powerful chaining inherent in ratio schedules (Ferster and Skinner, 1957). Each successive member of the sequence acts as a reinforcer for the previous response. In this experiment, the effect was sometimes sufficiently strong to generate new learning even without terminal reinforcement.

The observation that the animals tended to "hang up" at positions where lights had been turned objectively off suggests a technical refinement that might help them learn longer sequences. A fading procedure that permitted the correct keys at all serial positions to remain in the fading state even after the animal learned them might be more effective than any of the procedures used here. An additional technical refinement might be to require a correct completion of the entire sequence on a given trial, rather than simply requiring correct responses at the critical position before fading the key-light at that position.

REFERENCES

Boren, J. J. Repeated acquisition of new behavioral chains. *Amer. Psychologist*, 163, **17**, 421 (abstract).

Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.

Harlow, H. F. Learning set and error factor theory. In S. Koch (Ed.), *Psychology: A study of a science. Vol. 2*. New York: McGraw-Hill, 1959. Pp. 492-537.

Klüver, H. *Behavior mechanisms in monkeys*, Chicago: Univ. Chicago Press, 1933.

Ray, B. A. The course of acquisition of a line-tilt discrimination by rhesus monkeys. *J. exp. Anal. Behav.*, 1967, **10**, 17-33.

Reynolds, G. S. Attention in the pigeon. *J. exp. Anal. Behav.*, 1961, **4**, 203-208.

Sidman, M. and Stoddard, L. T. The effectiveness of fading in programming a simultaneous form discrimination for retarded children. *J. exp. Anal. Behav.*, 1967, **10**, 3-15.

Spence, K. W. The nature of discrimination learning in animals. *Psychol. Rev.*, 1936, **43**, 427-449.

Terrace, H. S. Errorless transfer of a discrimination across two continua. *J. exp. Anal. Behav.*, 1963, **6**, 223-232.

Thorndike, E. L. *The psychology of learning*. New York: Teacher's College, Columbia Univ., 1913.

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