PROGRAMMING STIMULI IN MATCHING TO SAMPLE¹

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In these investigations, a "teaching machine" was used to train pre-school and first-grade children in a series of progressively difficult discrimination tasks, leading up to matching to sample. Such training was much more efficient than training in the final discrimination alone. The errors the subjects made were found to be a function both of the differences between consecutive discriminations (the "size of the steps" in the program) and the length of training on each discrimination. Theoretical and practical implications of these findings are discussed.

"Teaching machines" were originally conceived as devices for applying powerful principles and techniques, derived from the study of learning in animals, to human instruction (Skinner, 1954); and they are ordinarily discussed in those terms (*cf.* Holland, 1960). Less has been said, perhaps because it has been taken for granted, about the use of teaching machines as instruments for studying human learning. Besides being used to apply known principles to practical tasks, teaching machines may be used as other pieces of operant-conditioning apparatus are used: to control the conditions under which learning occurs in order to study it better. Such research is not simply concerned with assessing the relative effectiveness of alternative programs or techniques. It is also concerned with showing how the results of one experiment are related to those of another.

The present research was the outgrowth of an effort to study concept formation in children while retaining contact with research on discrimination learning in animals. It made use of a type of teaching machine originally conceived by B. F. Skinner. The behavior studied was matching to sample.

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EXPLORATORY EXPERIMENTS

Apparatus

Figure 1 shows the apparatus. A slide projector inside the box projected stimuli onto the windows in the front panel. The top section of the panel was not used in these experiments. The center section consisted of a single, long window in which the sample stimulus appeared. The bottom section was di-

Fig. 1. Apparatus.

vided into four small windows, and the choice stimuli appeared in the middle two of these. The subject's task was to select the one of the two lower stimuli which matched the one above. He indicated his choice by pressing the window on which the stimulus appeared. This action closed a switch, and if the choice was correct, the projector automatically changed slides. (The apparatus detected the position of the correct choice photoelectrically.) If the choice was incorrect, nothing happened, and the subject could respond again immediately.

An approximately 270-g force, applied to the center of a choice window, was required to close the switch, which made a clearly audible "click." The control circuit required that a

White (1957): 32 cells were filled in an 8 by 8 matrix, and then 4 cells at a time were moved to new locations, starting from Form A and ending with Form D. These forms were plotted in successively larger matrices, transferred to *Color-Aids* papers of neighboring hues, mounted on uniform grey backgrounds, and photographed on *Kodachrome* film. They were projected "life" size.

Procedure

Subjects were brought to an experimental room one at a time by an experimenter who talked with them freely but did not discuss the experiment. In the room, she gave the following instructions:

(1) "This is a machine for you to play with." The experimenter turned on the projector, showing the first slide.

(2) "You can make it go like this." The experimenter operated the apparatus deliberately and correctly four times.

(3) "You do it." If the subject did not respond or stopped responding, the experimenter repeated instruction No. (2).

(4) After the subject had operated the apparatus four times, the experimenter said, "Good, see if you can push the right one every time," and retired to a chair about 8 ft behind the subject.

(5) Remarks the subject made during the session were ignored insofar as possible, or answered by, "See if you can push the right one every time."

(6) If the subject asked to leave, the experimenter said, "Wouldn't you like to do the rest?" If the subject insisted, he was allowed to go. At that time, or at the end of the session, the experimenter said, "All finished? Good, perhaps you can come back again another time."

Subjects were members of the first grade in the Franklin School, Lexington, Massachusetts. The 94 children were listed in order of age, from the youngest (5-8) to the oldest (6-10), and the list was divided into six equal groups. One child was chosen at random from each of these age groups to make up each experimental group of six subjects.

Experiment 1. This experiment presented a standard matching-to-sample problem in which each of the four stimuli appeared as a correct choice, in contrast to each of the others and in each of the choice windows, in

Fig. 2. Stimuli.

switch be held closed for 0.15 sec in order to record a correct choice. During this time, an incorrect response broke the circuit and reset the timer. Thus, subjects were prevented from operating the machine by simply pressing both choices at once. Changing slides required 0.75 sec, during which time the projection beam was broken by a shutter which remained closed until all window switches returned to the normal position. Responses and slide changes were recorded on a polygraph.

Figure 2 shows the stimuli, which differed systematically in shape, size, and color. They were constructed after a method described by

Fig. 3. Performances of subjects in Experiments I and II: A, Experiment I; B, Experiment II.

a "random" sequence. There were therefore 24 possible stimulus combinations (identified by two letters indicating the choice stimuli and their position, followed by a hyphen and a letter indicating which appeared as the sample): AB-A, AB-B, BA-A, BA-B; AC-A, AC-C, CA-A, CA-C; AD-A, AD-D, DA-A, DA-D, BC-B, BC-C, CB-B, CB-C; BD-B, BD-D, DB-B, DB-D; CD-C, CD-D, DC-C, DC-D. Each of these items was photographed four times. A Gellerman Series (Gellerman, 1933) was used to determine a sequence of right and left correct-choice positions, and slides were selected at random to fill each position. The resulting series of 96 slides was labeled *Series 4*, because it made use of each of the four different stimuli.

Six subjects were given Series 4, and in two subsequent sessions (on separate days) they repeated it. Figure 3A shows the number of errors made by each subject in consecutive groups of 10 slides. The last six slides in the series are not shown. Only errors made on the *first* response to each slide were counted; therefore, a subject responding at random to 10 slides would make 5 errors on the basis of chance. Points within a single session are connected; gaps in the records indicate the beginning of the next session. Subject 1 did not complete the program during any session.

No subject learned this discrimination within the three sessions, but all responded systematically in various ways. The most common were alternation and preservation with

Fig. 4. Items from Series 2SC0, Transition Series 1, and Series 2SC.

respect to the choice windows. However, subjects also favored one window or the other; followed the larger or smaller of the stimuli; pressed both windows at once; or played on the windows as if they were piano keys, switching frequently from one pattern of responding to another during a session.

I thought that subjects might respond to the matching relationship if they began with an easy discrimination and approached the matching task through a series of “successive approximations,” a procedure suggested by theoretical discussions of teaching-machine programming (Skinner, 1954; Holland, 1960).

The next experiments were attempts to develop such a sequence of progressively difficult discriminations leading up to the matching-to-sample task required in Experiment I.

Experiment II. Series 2C was designed to present an easier task than Series 4. It used only stimuli *A* and *D* (Fig. 2) Stimulus *A* always appeared in the left-hand choice window, and *D* in the right; only the sample changed. The two items used in this series are shown in Fig. 5, where they are labeled 2C(2). The items from Series 2C also are part of Series 2, which will be described later. Other items shown in Fig. 4 and 5 are from experiments which follow. Each was photographed 40 times, and the Gellerman series was used to determine the sequence in which the 80 slides appeared. The number "2," identifying this series of slides, indicates that two stimuli were used, and the letter "C"

indicates that the position of the stimuli in the choice windows was constant.

Six subjects were given Series 2C, and repeated it in subsequent sessions on separate days. After they had reached a criterion of 10 per cent error over the entire series, or had completed three sessions, they were given Series 4. Figure 3B shows their records. Subject 4 did not complete the series during Session 1, and Subject 3 did not complete it during any session.

Five subjects learned the task required by Series 2C; and when they were switched to Series 4, their records were similar to their records at the end of Series 2C. A comparison of Fig. 3A and 3B shows that the task required by Series 2C was in fact easier than that required by Series 4, and that pre-training on Series 2C facilitated the discrimination required in Series 4.

Fig. 5. Items from Transition Series 2, Series 2C, and Series 2.

Experiment III. Series 2SC0 and 2SC were designed to precede Series 2C. In Series 2SC the sample was located directly above the correct choice, rather than midway between the two. The letter "S," identifying the series, refers to this spatial relationship between the sample and the correct choice. Figure 4 shows the two items used in this series. The series contained 70 slides arranged in sequence using the Gellerman series.

Series 2SC0 was identical to Series 2SC, except that no incorrect choice stimulus appeared. The figure "0" refers to the absence of an alternative. The two items used in this series are also shown in Fig. 4.

Series 2SC0, 2SC, 2C, and 4 were presented in that order, all in one session. The apparatus shut off at the end of each series, and the experimenter said, "Good, now if you'll wait just a minute, I have some more for you to do." She then changed slide magazines and presented the next series.

Figure 6A shows the records of the six subjects who worked on this "program." All subjects responded correctly most of the time. The most errors occurred at the transitions from 2SC0 to 2SC and from 2C to 4, although there was considerable individual variation.

Experiment IV. Additional series were added to supply transitions from 2SC0 to 2SC, from 2SC to 2C, and from 2C to 4.

In the transition from 2SC0 to 2SC, the incorrect choice was introduced through four steps of increasing intensity. Figure 4 shows these steps. The two items were photographed with *Bourges Overlay Sheets* covering the incorrect choice-stimulus. These are transparent acetate sheets which are printed with a fine-dot pattern; the density of the dots provided 10 per cent, 30 per cent, 50 per cent, and 70 per cent grey "screens." Each item was photographed six times with each of the overlays. The Gellerman series was used to determine the sequence of the slides within each step.

In the transition from 2SC to 2C, the sample moved from a position directly over the correct choice to a position midway between the choices. Figure 5 shows the two steps in this series. The series contained 16 slides, 8 at each step, with the Gellerman series determining the sequence of slides in each step.

Series 2C was followed by Series 2, in which the stimuli now appeared at random in either

choice window. Figure 5 shows the four items used in Series 2. Each was photographed four times, and the 16 slides were assigned at random to positions in the Gellerman series.

Series 2 was followed by a transition series in which Stimuli *B* and *C* were introduced, but only *B* appeared in contrast to *D* and *C* in contrast to *A*. This series used eight items:

BD-B,	BD-D,	DB-B,	DB-D
AC-A,	AC-C,	CA-A,	CA-C

Each was photographed twice, and the 16 slides were randomly assigned to the Gellerman series.

The series were presented in order: 2SC0 (30 slides), Transition (24 slides), 2SC (40 slides), Transition (16 slides), 2C (40 slides), 2 (16 slides), Transition (16 slides), and 4 (94 slides). The first 130 slides (through the first 20 slides in Series 2C) were presented without interruption. The apparatus then shut off, and the experimenter said, "Good, now if you'll wait just a minute, I have some more for you to do." Then she presented the last 146 slides.

Figure 6B shows the records of the six subjects who worked on this program. Adding the transition series reduced the errors between Series 2SC0 and Series 2C and caused them to be distributed more widely. The total number of errors was reduced through Series 2C, but considerably more errors were made on Series 4 than were made by the subjects in Experiment III.

Experiment V. A number of slides were removed from the ends of Series 2SC0, 2SC, and 2C; but, otherwise, the material was identical to that used in Experiment IV. The program was: 2SC0 (20 slides), Transition (24 slides), 2SC (20 slides), Transition (16 slides), 2C (20 slides), 2 (16 slides), Transition (16 slides), and 4 (94 slides). The first 132 slides (up to the beginning of Series 4) were presented without interruption. The apparatus shut off, and the experimenter said, "Good, now then if you'll wait just a minute, I have some more for you to do." Then Series 4 was presented.

Figure 6C shows the records of six subjects who worked on this program. Through the end of Series 2C, this group made approximately the same number of errors as did the subjects in Experiment IV, but their performances on Series 4 were strikingly superior.

Fig. 6. Performances of subjects in Experiments III, IV, and V: A, Experiment III; B, Experiment IV; C, Experiment V; D, Group Performances.

The performances of subjects in Experiments III, IV, and V are summarized in Fig. 6D, which shows the total number of errors made by each group on comparable sections of their programs. The record of Group 3 is what one would expect from a set of transfer experiments: errors increase at the points of transition between series, and decrease throughout each series. The records of Groups 4 and 5 are considerably more irregular. An overall increase in errors is evident in the record of Group 4.

Putting the children through a program of progressively difficult discriminations clearly increased the efficiency with which they learned the matching task. Apparently, the smaller the "steps," i.e., the less difference between consecutive discriminations, the more efficient the program. But the effect of shortening sections of the program in Experiment V was quite surprising: Why should fewer errors occur in a short program than in a long one, if the two are otherwise identical? If length is a variable, did Group 5 perform better than Group 3 because the program had smaller steps, or because the steps were shorter, or both?

Two artifacts were possible in the exploratory experiments: One, subjects who learned the task might have told their friends how to do it; and, two, the experimenter might have become more skilled at instructing the subjects during the experiments. A control experiment was designed to replicate the exploratory experiments and to study the effect of program length somewhat further.

CONTROL EXPERIMENT

Programs

The *Criterion Program* was the same as Series 2 (Fig. 5): a random matching-to-sample task with two stimuli, rather than four. It contained 120 slides.

The *Standard Program* was identical to that used in Exploratory Experiment V, except that it ended with Series 2, to which four slides were added. The Standard Program thus consisted of the following series, totaling 120 slides: 2SC0 (20 slides), Transition (24 slides), 2SC (20 slides), Transition (16 slides), 2C (20 slides), and 2 (20 slides). Figures 4 and 5 show the items from each step in this program in order.

The *Expanded Program* was the same as the Standard Program, except that each series was approximately twice as long. It totaled 243 slides arranged in order: 2SC0 (48 slides), Transition (48 slides, 12 at each step), 2SC (48 slides), Transition (32 slides, 16 in step 1, 15 in step 2), 2C (48 slides), and 2 (20 slides).

The *Reduced Program* was the same as the Standard Program, except that each series was approximately half as long. It totaled 84 slides arranged in order: 2SC0 (12 slides), Transition (16 slides, 4 at each step), 2SC (12 slides), Transition (12 slides, 6 at each step), 2C (12 slides), and 2 (20 slides).

The *Abridged Program* was the same as the Standard Program except that all transition series were deleted and replaced by an equal number of slides from the series which followed. It therefore totaled 120 items: 2SC0 (20 slides), 2SC (44 slides), 2C (36 slides), and 2 (20 slides).

Procedure

The subjects were children in the Lesley Ellis School, Cambridge, Massachusetts. They were drawn from a kindergarten class, two "transition" classes, and two first-grade classes; and their ages ranged from 4-6 to 7-1. Two subjects were chosen at random from the kindergarten and one from each of the other classes to make up each experimental group of six. Table 1 shows the format of the experiment. Groups were run in the approximate order in which they are presented in the table, and a day or more elapsed between sessions.

The instructions and procedure were identical for all groups (except where noted below), and were the same as those described previously. Another experimenter was used.

Results

Figure 7 shows the records of subjects in Group S. The errors each individual made are plotted cumulatively against the slides in each program. Intervals on the vertical axis are twice as large as intervals on the horizontal axis. The height of a curve at any point shows the total number of errors the subject made up to that point. Changes in the slope of a curve show changes in the accuracy with which the subject responded. Chance performance would yield a slope of

Fig. 7. Performances of subjects in Group S.

45 degrees. (See Inset.) During periods when a subject was making no errors, his cumulated error curve is a horizontal line.

The number of errors made by subjects in Group S was not significantly different from that made by subjects working on the identical portion of the program in Exploratory Experiment V. The effectiveness of the Standard Program therefore cannot be attributed to communication between the children or to the behavior of the experimenter. [All comparisons, except where otherwise noted, are by the Mann-Whitney Test, using the 5% level of significance, *cf.* Mostellar and Bush (1954). For cases in which the results were predictable on the basis of the exploratory experiments, a "one-tailed" test was used.]

All subjects in Group C performed at a chance level throughout the first two sessions. The fewest errors any of the subjects in Group C made during either session was 60, whereas no subject in Group S made more than 15. This confirmed the major finding of the exploratory experiments: approaching the criterion task through a sequence of progressively difficult discriminations was much more efficient than training in the criterion task alone.

After two sessions on the Criterion Program, Group C was switched to the Standard Program. At the beginning of this session, the experimenter said, "Let me show you how to do it," and then repeated the usual instructions.

Figure 8 shows the records of Group C for this session. (The record of Subject 6 is set back to the base line at slide 100.) The effect of their previous work on the Criterion Program is clear: transfer to the Standard Program was negative. Only two subjects in Group C showed evidence of coming under control.

Figure 9 shows the records of subjects in Group A. (The record of Subject 6 in Session 2 is set back to the base line at slide 79.) Subject 4 did not complete the program during Session 1, and Subject 5 declined to return for Session 2. The number of errors these subjects made on the Abridged Program was significantly larger than that made by Group S on the Standard Program. They also made a significantly larger number of errors on the Criterion Program. Deleting the transition series increased the errors both in training and on the criterion task. Making the

Fig. 8. Performances of subjects in Group C, on Standard Program.

training programs equal in length amplified rather than decreased the effect.

Figure 10 shows the performances of subjects in Group E. The number of errors these subjects made in working through the Expanded Program was significantly larger than the number of errors the subjects in Group S made in working through the Standard Program. This confirmed the trend found in exploratory experiments.

One explanation of this difference might be that once a subject has learned the task required by any given series of slides the errors occur at random. A longer program would therefore allow more random errors to occur. However, the number of errors the subjects in Group E made on the Expanded Program (243 slides) was also significantly larger than the number of errors the subjects in Group S made on the Standard Program and the Criterion Program taken together (240 slides). Therefore, that explanation must be rejected.

Some of the errors Group E made might have been due to fatigue. The average length of Session 1 for Group S was 5 min, whereas it was 11 min for Group E. This explanation is ruled out by comparing the number of errors made by the two groups in Session 2, when both were fresh. The number of errors Group E made was significantly larger in this session as well.

The effect does not seem to be due simply to repetition of a given series. The number of errors Group E made on the Criterion Program in Session 2 was also significantly larger than the number of errors Group S made on the Criterion Program in Session 3, although at the beginning of Session 3, Group S had already worked through 140 slides from Series 2, whereas Group E had worked through only 20.

It still seemed possible that the lengths of the sessions might be contributing to the effect. Group S2 was run as a control for this ill-defined possibility. This group was given the Standard Program and two repetitions of the Criterion Program (totaling 360 slides) all during a single session which averaged 17 min in length. Figure 11 shows the performances of these subjects.

When the number of errors Group S2 made on the Standard Program and the first Criterion Program combined was compared

Fig. 9. Performances of subjects in Group A.

Fig. 10. Performances of subjects in Group E.

with the number of errors Group E made on the Expanded Program (equating both for the total length of the programs and the

amount of continuous running time), the difference was in the same direction as between Group S and Group E, but it fell short

Fig. 11. Performances of subjects in Group S2.

of significance. Comparing the number of errors Group S2 made on its second Criterion Program with the number of errors Group E made on its Criterion Program gave the same result, although in this case fatigue should have given the advantage to Group E.

If presenting all the programs within a single session rather than on separate days had any effect, it would have had to show itself in an increase in the number of errors from program to program in Group S2 compared with Group S. But the errors did not increase through the three programs for either group, and there was no reliable difference between the number of errors made by the two groups on the last program. If massing the trials had any effect upon the number or errors, it was certainly a very small one.

Figure 12 shows the performances of the subjects in Group R. Shortening the program also resulted in an increase in errors. The difference between the number of errors made by Group R on the Reduced Program and that made by Group S on the Standard Program was not significant, but the difference in errors made by the two groups on the

Criterion Program was quite large (and significant).

DISCUSSION

Krechevsky (1932) was one of the first to point out that the behavior of subjects in the "pre-solution period" of discrimination problems is not "random." In the records of individual rats, he found periods of systematic responding with respect to properties of the experimental situation other than the stimuli being manipulated by the experimenter, *e.g.*, position alternation, and perseveration habits. He noticed that the animals often responded systematically in several different ways before coming under control of the relevant stimuli, and he called these periods of systematic responding "hypotheses." Similar behavior was markedly evident in these experiments.

Skinner (1948) and Skinner and Morse (1957) have shown how "incidental" contingencies of reinforcement may straighten systematic responding in a free-operant situation. Periods of systematic responding in a discrimination can be interpreted in a similar way.

Fig. 12. Performances of subjects in Group R.

The experimenter defines the "correct hypothesis" in a discrimination experiment by arranging to reinforce a given class of responses in the presence of a given class of stimuli. In most discrimination experiments, however, a subject can respond to a variety of stimuli in a number of different ways, some of which may incidentally satisfy the requirements for reinforcement. In these experiments, pressing a choice window was reinforced by operation of the slide changer only when the stimulus occupying that window was identical to the sample stim-

ulus in the window above. However, there was no guarantee that subjects would observe the matching relationship. If a particular response to the correct choice window happened to be under the control of the properties of the specific choice stimulus, or of the spatial location of the window, it, too, was reinforced. Behavior which is thus incidentally strengthened might reasonably be called, in Krechevsky's terms, an "incorrect hypothesis."

The difference between a "correct hypothesis" and an "incorrect hypothesis" is a matter of the probability that the behavior will be reinforced. "Correct hypotheses" are consistently reinforced, and "incorrect hypotheses" received only chance reinforcement. In practice, the problem of minimizing the chances that "incorrect hypotheses" will be accidentally strengthened is complicated by the fact that the "randomness" of a series of correlations between the occurrence of an irrelevant stimulus and the availability of reinforcement depends upon the length of the series. Portions of a series selected with the help of a random number table, for instance, may be nonrandom enough to strengthen "incorrect hypotheses." A short, behaviorally random, sequence of correlations is quite difficult to design.

Furthermore, no matter how carefully one designs a sequence of correlations between the occurrence of stimuli and the availability of reinforcement, the actual contingencies of reinforcement in a given case depend upon what the subjects observes, which in turn depends upon the individual subject's history. From the experimenter's point of view, it is a matter of chance. Therefore, the chances that "incorrect hypotheses" will be strengthened are a function of the number of stimuli present. The more complex the discrimination problem, the less likely the subjects are to observe the relevant stimuli, and the more likely "incorrect hypotheses" will be incidentally reinforced.

Presenting the subject with a sequence of progressively complex discrimination problems may be thought of as a way of increasing his chances of observing the relevant stimuli in each problem. The increase in efficiency with which subjects in these experiments learned the matching task when it was preceded by such a program is therefore a measure of the degree to which the procedure pre-

vented "incorrect hypotheses" from interfering with the development of the discrimination.

If hypotheses were rejected by a logical process—if, for instance, one correct response "confirmed" a hypothesis, and one incorrect response "rejected" it—the number of errors

Table 1
Format of the Control Experiment

Group	Program		
	Session 1	Session 2	Session 3
Group S	Standard	Criterion	Criterion
Group C	Criterion	Criterion	Standard
Group E	Expanded	Criterion	
Group R	Reduced	Criterion	
Group A	Abridged	Criterion	
Group S2	{ Standard Criterion, Criterion }		

Table 2

Errors Made by all Subjects Working on the Standard Program and on the Abridged Program from the End of Series 2SC0 to the First Group of 10 Consecutive Correct Responses in Series 2SC

Errors	Frequency			
	Standard Program		Abridged Program	
	Exploratory Exp. V	Control Group S	Exploratory Exp. III	Control Group A
0	1	2		
1	2		1	1
2	1	1	1	
3				
4				
5		1	1	
6	1	1		1
7	1			
8				
9				
10		1		
11			1	
12			1	1
13				1
14				
15				
16				
17				
18				
19				
20				
21				1
22				1*
23			1	
24				
25				

* Subject did not reach criterion before the end of the series.

subjects made in learning a complex discrimination would be larger and more variable than the number of errors subjects made in learning a simple one; but the longer a subject worked on either problem, the closer he would come to the solution. Although none of the subjects in Group C learned the task required by the Criterion Program within two sessions, they might eventually have learned if the experiment had continued long enough. However, the performance of Group C on the Standard Program *reduced* the likelihood that they would respond to the relevant stimuli. Two explanations for this finding are possible.

The contingencies of reinforcement arranged by the apparatus may have been somewhat unstable. Pressing a window required very little effort, and an incorrect response could be followed immediately by a correct one. It may have been easier to respond to position cues or to the properties of the choice stimuli and to switch after errors, accepting 50 per cent reinforcement, than to observe the matching relationship. In this case, the Standard Program may simply have prevented subjects from discovering an easier way to operate the apparatus. None of the subjects in Group S, for example, found out that the slide changer would not operate if both windows were pressed at once, because none of them tried it. However, the records of Group C in Session 2 did not show specific stable patterns of responding, as would be expected if subjects had hit on an easy way of operating the machine. Instead, several patterns alternated with one another. A more reasonable explanation of the performance of Group C on the Standard Program is that response patterns established under intermittent reinforcement in the Criterion Program conflicted with the observation of the relevant stimuli.

Randomizing the relationship of irrelevant stimuli to reinforcement guarantees that responses to them will be intermittently reinforced. In effect, a subject who is responding to a stimulus which has a 50 per cent correlation with reinforcement is working on a variable-ratio schedule with a mean ratio of two responses. In an insoluble discrimination, one might expect subjects to respond to one irrelevant stimulus and then to another, in the same way that animals alternate between responses maintained on equally profitable

concurrent schedules (Herrnstein, 1958); but one would expect that these irrelevant stimuli would acquire substantial control which would conflict with the establishment of control by a new stimulus. The form of the records in Fig. 8 supports this interpretation. Only Subject 6 performed at a chance level from the beginning of the session. In the records of the other subjects who failed to learn the matching task, errors do not gradually increase, but occur as sharp discontinuities in the curves (marked by the letter "D" in the records). This is what would be expected if strong behavior intruded when the stimuli which controlled it appeared.

If deleting the transition series made it less likely for subjects to observe the relevant stimuli in the series that remained, one would expect subjects in Group A to make more errors, on the average, than those in Group S, and their performances would be more variable. The data from these two groups support this interpretation (Fig. 7 and 9). As would be expected, discontinuities appear in the records of subjects in Group A at the divisions between series, but they do not appear at the same divisions for all subjects; and the number of errors occurring before the curves level out again is quite variable. In contrast, the errors made by Group S were spread more evenly across the first session, except for the group of errors made by Subject 6 in Series 2SC. The points where errors occurred were not correlated with each other or with the steps in the program.

A clearer picture of the increase in variability caused by deleting the transition series is shown in Table 2, where the number of errors made in reaching a criterion of 10 consecutive correct responses on Series 2SC is compared for subjects working on two "abridged programs" and on two "standard programs."

The performance of Group A on the Criterion Program was surprising. Most of the errors made by Subjects 1, 2, 3, and 4 occurred after considerable periods of correct responding. The same phenomenon appears in the records of Group E (Fig. 10) in a more pronounced form, and to a somewhat lesser extent in Group R (Fig. 12). There is no immediately obvious reason why the number of errors occurring *after* learning should be a function of the training procedure.

In keeping with the interpretation of Group C's performance on the Standard Program, these "postlearning" errors may represent the intrusion of systematic forms of responding which had been incidentally strengthened during training. This explains why Group S made fewer postlearning errors than Group A: if the effect of the Standard Program was to make it more likely for subjects to observe the relevant stimuli and therefore less likely for "incorrect hypotheses" to be incidentally reinforced, then Group S had fewer "incorrect hypotheses" which were available to intrude later.

Two bits of evidence support this interpretation. (a) In general, the number of errors made by all subjects following the first substantial period of correct responding on the Criterion Program was correlated with the number of errors made up to that point. For subjects in the control experiment, the correlation between the number of errors made before the first group of 10 consecutive correct responses on the Criterion Program, and the number of errors made after that point was .63 (Pearson Product Moment Coefficient). (b) In the records of subjects who made a large number of postlearning errors, the errors both before and after learning tended to occur in groups, as would be expected if "incorrect hypotheses" were intruding.

This explanation is not entirely satisfactory. In the Criterion Program, the characteristic performance of nearly all subjects who learned the task was a more or less extended period of correct responding, followed by an increase in the slope of the error curve in which errors alternated with further periods of correct responding. In the records of subjects who made a large number of postlearning errors, this increase in slope often appears as a pronounced discontinuity in the curve. (Points where this discontinuity appears are marked "D" in Fig. 9 and 10.) A similar trend appears in many of the records of subjects in Groups S and S2 (Fig. 7 and 11), although these subjects made very few postlearning errors. If postlearning errors were caused by the intrusion of behavior which was incidentally reinforced during the learning period, one would expect the error curves in the entire criterion session to look like the portions which follow the discontinuities. What caused the curves to level out first?

The periods of errorless responding may have been due to an artifact in the procedure. They tended to appear at the beginning of the criterion session, and, in the records of Group S2, immediately after the experimenter reloaded the slide projector. The presence of the experimenter at these points may have acted as a supplementary source of motivation, which diminished as the session progressed. The record of Subject 4, in Fig. 10, shows the effectiveness of such supplementary motivation. At the beginning of the second session, the experimenter, contrary to the usual procedure, said, "This is an important job. I want you to work hard at it, with no nonsense." A considerable period of correct responding followed, which was broken by the clusters of errors appearing in the middle of the section. At "I," the experimenter said, "You're not paying attention; try to press the right one every time." Another period of correct responding followed, but the session ended with another cluster of errors.

Supplementary motivation due to the experimenter cannot account for periods of correct responding at the ends of the sessions, however. Another interpretation is attractive, because it helps to account for the inferior performance of Group E.

Three reasons why the operation of the slide projector acted as a reinforcer in these experiments are possible: (a) The subjects were told to "try to press the correct one every time," and they may have been working to please the experimenter or to reduce an implicit threat. (b) Operation of the slide projector resulted in stimulus change, and several studies have shown that such stimulus change may act as a reinforcer (*cf.* Berlyne, 1960). (c) Operation of the slide projector resulted in changes in *stimulus control*. Responding correctly under conditions of changing stimulus control possibly is reinforcing in itself. In a situation in which social motivation is minimized, as in these experiments, the effects of the latter two reinforcers should reveal themselves. Whether one or both of them were operating (and it may not be possible to separate the two), the effects would be the same. In a given series of slides, observing and responding to the relevant stimuli are reinforced by the presentation of novel items. As responding continues, the stimuli (and the task) become less and less novel, and observing

should decrease. One would expect "careless" errors to occur, and eventually the subject should stop responding or respond to other properties of the apparatus. If supplementary motivation is added at this point, one would expect observing to occur as a kind of "avoidance response," maintained by occasional errors which result in punishment or loss of reward. On the other hand, if the series gives way to another, slightly different set of stimuli (and slightly different task), observing and correct responding should be maintained at a high level, reinforced by the appearance of novel items. The most effective moment to switch from one series to the next would be when correct responding is firmly established, but while observing is still at a high level, so as to maximize the chances that the subject will respond correctly to the new stimuli. If changes were made after observing had partially extinguished, they might go unnoticed for a time; and when observing did occur, the chances that the new stimuli would elicit an "incorrect hypothesis" would be increased. The subject might learn the task required by the new series; but once he was responding correctly, observing the relevant stimuli should again extinguish, and behavior which had previously been incidentally reinforced should reappear, making it less likely that the subject would notice the next change. The process would be cumulative, and the records of the subjects should show increasingly large groups of errors interspersed with periods of correct responding. This is a reasonably adequate *post hoc* description of the behavior of the subjects in Group E.

A similar explanation accounts for discontinuities in the records of subjects working on the Criterion Program. Subjects responded correctly until the monotony of the material caused responding to relevant stimuli to extinguish so that other behavior intruded.

The records of the subjects in Group R show that changes from one series to the next can take place too rapidly, as well as too slowly. In this case, the effect seems to be similar to that of the Abridged Program: Errors tend to occur in groups, associated with the points of transition between series; and a large number of errors occurs on the Criterion Program. Why longer periods of correct responding do not appear on the Criterion Program remains unexplained.

The preceding account is quite speculative, but it suggests several lines of research. How much the results were due to unstable contingencies of reinforcement can be assessed by varying the amount of effort involved in responding, for example, by requiring the subjects to respond to the correct window more than once in order to operate the apparatus. The effects of "extrinsic" motivation can be investigated by adding a score-counter or candy dispenser, or by causing errors to turn the apparatus off and requiring subjects to work to turn it on again.

The most interesting possibility is that responding correctly under changing stimulus control is automatically reinforcing. A particularly good way of studying this effect might be to switch individuals from one series to the next after a given number of responses at a given percentage of error and to study their behavior as a function of the criterion run.

IMPLICATIONS

These experiments confirm the findings of Lawrence (1952), North (1959), and Spiker (1959) that learning is more efficient, in terms of either trials or errors, when training in a difficult discrimination is preceded by training in similar but easier discriminations, than when all training is given in the difficult discrimination alone.

Lawrence (1955) pointed out that these findings pose a problem for theories of discrimination learning: "Usually it is assumed that a fixed amount of practice is most profitably spent if all of it is devoted to training on the specific task on which the individual will be tested." He went on to show that the findings are difficult or impossible to account for in terms of generalization gradients.

However, Lawrence did not mention that his paradox rests upon the assumption that discrimination learning is "continuous." What to expect from a "fixed amount of training" on the "task on which the individual will be tested" is the question raised in the continuity-discontinuity controversy (*cf.* Blum & Blum, 1949).

McCulloch and Pratt (1934) gave the continuity-discontinuity problem its first, and probably its clearest, statement:

"The assumption seems to be implicit in nearly all reports upon sensory discrimination

in the white rat that some quantitative aspect of the animal's performance preceding the solution, usually represented in terms of trials, errors, or time, reflects directly the capacity of the animal to make the discrimination.

"... It is conceivable that the point at which an animal adopts the correct solution is dependent upon chance factors, *i.e.*, factors extrinsic to the animal's ability to form the discrimination concerned . . .

"If Lashley were correct in his interpretation that 'the practice preceding . . . is irrelevant to the actual formation of the association,' the measurement of a rat's ability in terms of the amount of practice preceding the solution would obviously be subject to criticism . . .

"If . . . it can be demonstrated that repetitive training produces a cumulative effect irrespective of the 'hypothesis' being tested, a summation of scores may be taken as representative of an animal's ability on a given task" (McCulloch & Pratt, 1934, p. 271).

Ehrenfreund (1948) showed that whether or not training produces a cumulative effect depends upon whether or not the experiment is designed so that subjects are likely to observe the relevant stimuli. The results of the present experiments may be considered an extension of Ehrenfreund's findings. If one accepts the argument developed above, that a program of successive discriminations makes it more likely for subjects to observe the relevant stimuli and therefore less likely for "incorrect hypotheses" to be incidentally reinforced, then the amount by which such a program increases learning efficiency must be a measure of the degree to which learning the criterion task alone is "dependent upon chance factors."

The method of approaching a discrimination through a series of successive approximations is offered here as a way of taking the discontinuities out of any discrimination experiment. The procedure may not resolve the controversy of continuity vs. discontinuity, but it seems to reduce it to another set of questions:

(1) If one wishes to know how likely it is for subjects to observe certain stimuli or respond to certain relationships—*e.g.*, do birds respond to visual stimuli more readily than rats?—then the classical discrimination experiments referred to by McCulloch and Pratt are valid.

(2) If one wishes to know whether subjects are *capable* of responding to a given relationship—e.g., the “conditional discriminations” described by Lashley (1938) or the present matching-to-sample task—it would seem more reasonable to approach the criterion task by a series of successive approximations and to observe where the performance breaks down. In the present experiments, for example, one might expect a subject “incapable” of responding to the matching relationship to begin making errors as the sample was moved to a point midway between the choice stimuli.

(3) If one is interested in how subjects go about discovering which of a given set of stimuli is correlated with reinforcement or in the capacities of subjects to solve such a problem, an experiment in which subjects are first trained to observe the component stimuli and then are required to “discover the concept” is indicated (*cf.* Harlow, 1949).

(4) One may be interested in whether or not discrimination learning is “continuous,” in the sense that more than one reinforcement is necessary to “confirm a hypothesis,” and to what extent some individuals learn more quickly than others, *i.e.*, require fewer reinforcements. Some of the data from the present experiments relate to the first of these questions. The effect of the Standard Program lends itself to a Guthrie interpretation (Guthrie, 1935); *i.e.*, the program was effective because gradual changes in stimulus control insured that new stimuli were introduced in such a way as to prevent incorrect responses from being elicited. If this were a matter of strict contiguity, shortening the series should have had little effect, so long as each of the items in each series appeared at least once. The performance of Group R suggests that this is not the case, but the question should be pursued further.

These experiments raise a related question. Discrimination is ordinarily described as a process of differential reinforcement (*cf.* Spence, 1936; Skinner, 1938; Hull, 1950). If responses to the negative stimulus are strong, whether through generalization from the positive stimulus or through prior training, the only mechanism which can weaken them, according to this interpretation, is nonreinforcement (disregarding punishment). The fact that errors occurred when subjects working on the Abridged Program were switched

from Series 2SC0 to Series 2SC would seem to indicate that the negative stimuli in Series 2SC had acquired some control over the choice-response through training in Series 2SC0. There is no clear reason why gradually increasing the intensity of these stimuli, as was done in the Standard Program, should have weakened their control. When they reached their full intensity, they should have elicited a proportionate number of errors. The fact that they did not do so, and that 5 of the 18 subjects who worked on the Standard Program made no errors on Series 2SC, is rather surprising. Subject 1 in Group 6 and Subject 1 in Exploratory Experiment 5 learned the task required by the Criterion Program without making an error. In subsequent experiments, this phenomenon has become commonplace. These children learn the matching task without discovering that pressing an incorrect window does not operate the machine.

One purpose of these experiments was to see how practical an apparatus of this sort might be for teaching discriminative and conceptual behavior to children. Two related findings appear to have special practical importance.

(1) The more errors the training procedure allowed children to make, the more they tended to go on making. What would happen if the subjects who learned the task required by the Criterion Program were all given a further program—for example, one in which the number and similarity of the stimuli were gradually increased? This has not yet been tested, but it seems likely that differences in performance will be related to differences in performance on the Criterion Program. In the present situation, there appears to be a progressive loss of control. After a bad program has been tested, it can be revised, but the subjects must be thrown away. Additional “extrinsic” motivation may minimize post-learning errors for all children, regardless of the training procedure, but this remains to be investigated.

(2) Programs can be too long as well as too short or too discontinuous. It may be possible to come empirically to programs which are an effective length for most children; the Standard Program was reasonably adequate in this respect. Again, additional sources of motivation may make the performances of

subjects more consistent, both by reducing the number of postlearning errors and by decreasing the aversive effects of the program for those subjects for whom it is too long. On the grounds of efficiency, however, one would prefer to let subjects proceed to the next task as rapidly as possible after mastering the first. Requiring a child to work through truly repetitive material beyond the time when he could effectively pass on to the next task is educational "lock-step" in a teaching machine.

Operant-conditioning studies with children (cf. Bijou, 1955, 1957; Long, *et al.*, 1958) have shown how hard it is to maintain behavior on a repetitive task. The apparatus for programming additional reinforcement or punishment in the present discrimination task may be both elaborate and unnecessary. An abundance of anecdotal evidence suggests that the reinforcing effect of responding correctly under conditions of changing stimulus control may be real. Teachers who have worked with individual students, and parents who have played with small children—setting them problems which differ just enough to "challenge" them—will be the first to affirm the motivating effect of the procedure. If such an effect is found in the present situation—and the way to find it is by switching subjects to the next series after some given criterion run—it will be a truly "intrinsic" motivation. It will not be surprising if it turns out to be a powerful one.

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