SUCCESSIVE REVERSALS OF A CLASSICALLY CONDITIONED HEART-RATE DISCRIMINATION¹

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Rats were trained to criterion in successive reversals of a classically conditioned heart-rate discrimination. Criterion was attained more rapidly in the later reversals in the series than in the early reversals and the inter-problem learning curve was of the same general form as that found with successive instrumental discrimination reversal in the same species.

One of the most critical questions in the psychology of learning is the nature of the relation between the two basic laboratory operations for producing changes in behavior: classical (respondent) and instrumental (operant) conditioning. One widely held view among learning psychologists is that the two conditioning procedures can be distinguished in terms of the class of behavior to which they apply and by the principles of learning involved (Mowrer, 1947; Schlosberg, 1937; Skinner, 1935). Classical conditioning is said to be applicable to responses of the smooth muscles and glands, and the behavior change is assumed to occur by virtue of temporal contiguity between a stimulus which initially elicits the behavior (the unconditioned stimulus) and an initially neutral stimulus (the conditioned stimulus). Instrumental conditioning, on the other hand, is said to apply to skeletal musculature, and the change is assumed to be primarily dependent upon the action of reward or punishment following the response. However, as two reviews attest (Kimmel, 1967; Rescorla and Solomon, 1967) current research questions the assumption that the two learning processes can be separated by these criteria and points up the interdependence of classical and instrumental phenomena.

Evidence on this issue has been sought in several ways. One involves attempts to condition instrumentally responses generally thought to be conditioned only by classical

procedures (*e.g.*, Kimmel, Sternthal, and Strub, 1966; Miller and Carmona, 1967; Miller and DiCara, 1967). A second technique studies the transfer from discriminative classical to discriminative instrumental conditioning involving the same reinforced and nonreinforced stimuli (*e.g.*, Bower and Grusec, 1964; Solomon and Turner, 1962; Trapold, 1966). Another strategy, which the present study followed, is to determine the similarity of the functions yielded by the two kinds of learning in response to fundamental training operations. Kimble's review (1961) lists a number of basic training variables (*e.g.*, delay of reinforcement) which appear to influence classical and instrumental conditioning in the same ways, but points out that such findings are not without important exceptions. One significant training condition for which comparison data are lacking is that of training on successive discrimination reversals. When organisms are given training of this type under an instrumental conditioning paradigm, a gradual but striking increase in speed of learning the reversal is often observed. The development of such learning sets is widely recognized as one of the most important phenomena of instrumental learning, but there has been little work on transfer in successive classical conditioning and it is not known whether a comparable phenomenon might characterize the learning of an extended series of classically conditioned discrimination reversals. The present experiment provides evidence on this question.

METHOD

Subjects and Apparatus

Two female albino rats of the Sprague-Dawley strain, approximately 150 days old, were

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housed in individual cages with food and water freely available throughout the experiment. During conditioning each animal was placed inside an E & M Instrument Co. rat holder. The holder consists of a piece of $\frac{1}{4}$ -in. thick transparent plastic contoured to a U-shape to fit closely around the animal. This unit is 6 in. long and 2 in. in maximum width and height, and is anchored to a metal base which forms the floor of the housing. Ventilation holes are placed along the length of the housing and three vertical guide holes are provided on either side for insertion of subcutaneous needle electrodes. The holder was placed inside a 10 by 12 by 16 in. (inside dimensions) black box designed to isolate the subject from extraneous stimulation and facilitate detection of the reinforced (CS+) and nonreinforced (CS-) training stimuli. On the wall facing the animal, approximately at eye level, were two circular pieces of frosted Plexiglas each covering an incandescent bulb mounted on the outside of the box. One of these stimulus discs (L1) was 3 in. in diameter and covered a 100-w bulb positioned to the left of the subject's head. The other stimulus (L2) was 1.5 in. in diameter and covered a 6-w bulb positioned to the right of the subject's head. Thus, L1 and L2 differed in position, size, and brightness. The midpoint of the animal's head was approximately 4 in. from the center of each stimulus. The box was covered by a 4.5-in. deep lid, the bottom of which consisted of a sheet of frosted Plexiglas which formed the ceiling of the chamber. A 40-w bulb was mounted inside the lid. The shock circuit consisted of a Heathkit battery eliminator, Model 1P-12 and a Harvard Apparatus Co. Model 308 inductorium. Shock was delivered through lead plate electrodes covered with EKG contact paste and taped across the subject's tail near the base about $\frac{1}{4}$ -in. apart. The tail, in turn, was taped firmly to the stand of the restraining tube. Resistance across the tail measured with the electrodes in place was approximately 35,000 ohms.

Recording was by means of a Grass Model 7 polygraph with tachograph pre-amplifier model 7P4AB. This provided a continuous write-out of beat-to-beat changes in heart rate. Heart beat was picked up by two subcutaneous needle electrodes which were inserted in either side of the animal just behind the forelegs and held in place by the guide holes pro-

vided in the sides of the restraining device. The metal base of the holder was grounded. The durations and relations of the conditioned stimulus (CS) and unconditioned stimulus (UCS) were controlled by Hunter timers. A 65-db (re 0.0002 dynes/cm²) white-noise source was positioned outside the box adjacent to ventilation holes drilled along the side.

Procedure

Before conditioning, the animals received six daily training sessions devoted to measuring and adapting the heart-rate response to the training stimuli. On each day L1 and L2 (the to-be-conditioned stimuli) were successively presented five times in a random order. Stimulus presentations lasted 11 sec each and were separated by 2-min intervals. During presentations of L1 and L2 the overhead light was off. These adaptation sessions were discontinued after six days because the unconditioned responses (UCRs) to the training stimuli were generally of small magnitude at that time (see Fig. 1).

The conditioned response (CR) was defined as a difference of at least ± 40 beats per minute (bpm) between the temporal points of initiation and tenth second of the CS. Several considerations entered into the selection of this criterion. First, the criterion change was selected so as to exceed the magnitude of the UCRs to the training stimuli at the terminal stage of adaptation. On the final day of adaptation trials, Rat A's mean change in heart rate during presentations of the training stimuli was +20 bpm with a range of 0 to +30 bpm. For Rat B, the mean change was +22 bpm with a range of +5 to +35 bpm. Second, the criterion magnitude was set to overlap the magnitude of UCRs to shock as observed in another sample of rats. In this test, two rats were placed in the holder and given 20 shocks (5.0 v) to the tail at intervals of approximately 5 min. The median UCR to shock was +90 bpm while the smallest UCR of each subject lay between +35 and +40 bpm. Finally, the criterion permitted both accelerative and decelerative changes in heart rate since both types of changes have been reported in different experiments (de Toledo and Black, 1966; Stebbins and Smith, 1964) and within the same experiment (Fehr and Stern, 1965); little is known as yet about the conditions associated with such differences.

In the test sample of rats it was also observed that after each shock the heart rate usually returned to the vicinity of the pre-shock rate within 2 min, but sustained elevation of heart rate or sustained high variability was occasionally observed. Therefore, as a matter of subsidiary interest, it was decided to compare the effects of a fixed intertrial interval training procedure with one in which the intertrial interval was contingent upon the appearance of a relatively low and stable rate. Rat A received CS-UCS pairings with fixed 2-min intertrial intervals. For Rat B, if heart rate changed during the course of a trial (*i.e.*, a change of ± 40 bpm), the next trial was presented when (a) the rate had returned to the pre-trial level and (b) this rate had been maintained for a 30-sec period with fluctuations of no more than ± 20 bpm. If heart rate did not change during the course of stimulus presentation or during the next 30 sec, the next trial was presented.

The CS consisted of the offset of the overhead 40-w light simultaneous with the onset of either L1 or L2 for a period of 11 sec. Shock was presented during the last second of the CS. The overhead light returned with CS offset and remained on throughout the intertrial interval. Five levels of shock (2.4 v, 3.7 v, 4.9 v, 6.6 v, and 8.0 v) were randomly presented with CS+ on the assumption that such a procedure would reduce adaptation to shock. Daily training time was about 1 hr for each subject, during which Rat A received 20 successive discrimination training trials and Rat B received 10 trials. Throughout training each subject was given a 10-min adaptation period with the overhead light on and the electrodes in place before the daily conditioning trials were started.

The criterion of discrimination learning was the appearance of at least eight CR's during 10 consecutive presentations of CS+ coupled with no more than two CR's to the intervening presentations of CS- which, due to the random order employed, varied from 8 to 10 in number. As soon as criterion was reached, a discrimination reversal was initiated (*i.e.*, CS+ became CS-, and *vice versa*) and training continued to the same criterion. Thus, reversal might be, and usually was, initiated within a daily training session. Successive reversals were accomplished in this manner throughout training.

RESULTS

Rat A was trained for approximately four months (20 trials per day) during which it completed 18 reversals. Rat B was trained for about nine months (10 trials per day) and completed 16 reversals.

Nature of the Conditioned and Unconditioned Response

Heart rates were taken directly from the continuous write-out of rate provided by the Grass Tachograph pre-amplifier. The magnitude of the CR was measured by computing the difference between the heart rate in bpm at the temporal point of initiation of the CS and at the tenth second of the CS. The UCR magnitude was the difference between the former value and the bpm reading after shock-induced movement, which generally persisted for 3 to 4 sec after shock, terminated. Figure 1 shows characteristic CR and UCR recordings for each animal.

Of the 743 CR's observed in the course of conditioning Rat B, 730 or 98% were decreases in heart rate, while all of the 652 CR's observed during Rat A's training were decreases. For both animals, the UCR was invariably an increase in heart rate. Typical heart rates and heart-rate changes of each animal under various conditions of the experiment are indicated in Table 1. These data indicate that the magnitude of the CR was relatively constant throughout training. However, the magnitude of the UCR of both animals decreased with training, suggesting adaptation to the shock.

The effect of the various shock levels upon the UCR was measured by determining the median UCR magnitude during the first 11 presentations of each shock intensity to each subject. For Rat A, these median values for the five levels of shock from lowest shock to highest are 100, 115, 110, 100, and 90 bpm. For Rat B the medians are 125, 120, 120, 100, and 110 bpm. These measures suggest that the shock stimuli did not differ appreciably in intensity. (The shock levels had been selected on the basis of a small number of observations in another sample of rats.) However, it is also possible that the use of randomly distributed varying levels of shock increased the uniformity of the UCR from trial to trial.

Nothing in the data points to a marked dif-

Fig. 1. Illustrative recordings of heart rate showing response of Rat B to CS presentation on the first trial of adaptation (record A) and on the final adaptation trial (record B), and a typical CR and UCR of Rat A (record C) and of Rat B (record D) taken from reversals midway in the series. Within each record the pips on line number 1 register 1-sec intervals while the solid band indicates CS presentation (records A and B) or CS and UCS presentation (records C and D). Line number 2 is a record of beat-to-beat changes in heart rate and line 3 is the EKG record. The arrow in each record points out the chart line corresponding to a heart rate of 400 bpm and the smallest chart divisions mark changes of 20 bpm.

Table 1

Median and range of CR and UCR magnitude and of heart rate in beats per minute at CS onset during the criterion trials of several reversals.

Reversal Number	Subject	Heart Rate at CS Onset		CR Magnitude		UCR Magnitude	
		Median	Range	Median	Range	Median	Range
1	A	345.0	330-390	62.5	40-90	65.0	40-95
1	B	360.0	345-405	60.0	40-125	120.0	85-135
9	A	377.5	325-435	60.0	40-100	60.0	25-110
7	B	387.5	355-400	82.5	50-95	90.0	50-135
17	A	400.0	355-425	70.0	45-110	45.0	15-80
15	B	387.5	380-420	67.5	40-90	60.0	30-80

ference in the effect upon conditioning of the two intertrial interval procedures. In regard to overall reversal learning, the subjects were similar in terms of the number of problems learned and speed of learning, as measured by number of trials (see below). As seen in Table 1, initial heart rates and CR magnitudes were also similar while the difference in UCR magnitude between subjects was apparent from the beginning of training. Of course, the durations of the intertrial interval differed under the two procedures, but this difference progressively decreased with training. Thus, the mean duration of the intertrial interval for Rat B during the first conditioning was 207.9 sec, but the mean duration reduced to 130.1 sec during the seventh reversal and to 119.8 sec during the final reversal.

Conditioning during Successive Reversals

Figures 2 and 3 depict the number of errors to criterion during the successive reversals by each animal. An error is defined as the failure to make a CR in the presence of CS+ or the appearance of a CR in the presence of CS-. In the initial discrimination only 26.1% of Rat A's errors and 25.7% of Rat B's errors were of the latter type. But considering the data of all reversals, 77.6% of Rat A's errors and 73.1% of Rat B's errors consisted of a CR to CS-, i.e., to the previous CS+. This distribution of errors was quite constant throughout successive conditionings. Thus, the percentage of errors which were CR's to CS- during successive sixths of Rat A's total reversal training were 74.4, 85.8, 79.8, 81.4, 81.9, and 79.7. A breakdown of Rat B's conditioning yields a similar result.

As shown in Fig. 2 and 3, both subjects showed marked changes in speed of reversal

learning with successive reversals. The median error score during the 18 reversals learned by Rat A was 26 errors, and during the 16 reversals by Rat B was 27 errors. For Rat A, eight of the last nine reversal error scores (i.e., the last half of the reversal series) lay below the median of its reversal series. For Rat B, six of the eight error scores comprising the last half of its reversal series were below the median value while two fell at the median. A similar pattern emerges when trials to criterion are considered. For Rats A and B, the median number of trials to criterion during their reversal series were 59 and 55, respectively. In the case of both animals, all but one of these scores were below the median during the last half of the reversal series. By the median test (Siegel, 1956) the probabilities associated with each of these error and trial score classifications are all < 0.005 . Thus, it can be concluded that for each subject, reversal learning during the latter half of the reversal series was easier than during the first half. Comparisons between the later reversals and the very first reversal are complicated by an interaction between CS value and speed of learning. As it happened, each animal made its initial reversal to the stimulus value associated with relatively faster learning throughout the series (although this value differed for the two animals). Nevertheless, as inspection of Fig. 2 and 3 reveals, the error scores for the last four reversals by Rat A and the last five reversals by Rat B are less than the error score of the first reversal problem. It might be noted that the differential effect of L1 and L2 upon speed of learning also accounts for much of the irregularity of the learning curves. Thus, if curves are drawn to connect alternate plotted points of Fig. 2 and 3 (i.e., to provide separate curves

Fig. 2. Total number of errors to criterion by Rat A during the original learning (OL) and during each reversal (1-18).

for reversals to L1 and to L2), the changes in errors with successive conditionings can be seen to follow a considerably smoother course.

Rat B had relatively little difficulty in learning the first reversal. This anomaly may have resulted from the operation of two factors. First, as noted above, this reversal involved the presentation of the subject's "preferred" stimulus as the CS+. Second, five of the CR's to CS+ during the criterion run which terminated the original learning were increases in heart rate. Since only 13 accelerative CR's appeared during the entire course of conditioning this animal, the composition of the criterion performance during its original learning was unique. Thus, there is some basis for questioning whether the learning which took place during the first reversal was the same as that which took place in the later reversals.

DISCUSSION

There is a striking resemblance between the error curves generated under the training conditions of the present experiment and the error curves reported for instrumental reversal

learning in the rat with both position and brightness discriminations (Dufort, Guttman, and Kimble, 1954; Fritz, 1930; Krechevsky, 1932; North, 1950a, 1950b; Pubols, 1957). As in the present experiment, successive reversal learning under instrumental procedures yielded a sharp rise in errors during the early reversals, followed by a progressive and marked improvement in performance. The initial deterioration in instrumental reversal learning generally has been found to reach its peak during the first two or three reversals, and this is also true of the classically conditioned reversals. The degree of improvement in instrumental reversal learning by the rat has been found to approximate or exceed that observed in the present study, sometimes reaching the level of so-called "one-trial" learning. One-trial learning is said to occur when the rat responds incorrectly on the first trial of a reversal, but correctly on all subsequent trials. However, it should be noted that the appearance of this phenomenon in the rat has been confined to the relatively simple case of position reversal learning. It is also a common finding that the level of performance fol-

Fig. 3. Total number of errors to criterion by Rat B during the original learning (OL) and during each reversal (1-16).

lowing an extended series of instrumental reversals is superior to that exhibited in the original learning and in the first reversal, but does not attain the status of one-trial learning. The terminal performances of the animals in the present study, especially those of Rat A, appear to fall in this category. It is an open question as to what effect further reversal training might have had upon error scores in the present experiment. But extrapolating from the error curves, it is not unreasonable to expect some further, albeit gradual, reduction with additional training.

Thus, the transfer relations observed during the successive classically conditioned heart-rate discriminations are similar to those which characterize the learning of a series of similar instrumental discriminations by the same species. Clearly, additional samples of tasks, test conditions, and subjects are required to establish the generality and limits of this similarity. But the present demonstration that rapidity of classical discrimination conditioning

can be increased by training on a class of discriminations provides evidence of a hitherto seldom considered degree of commonality between the two conditioning procedures with respect to this important parametric variation.

A number of mechanisms have been postulated to account for the appearance of such common properties in the two conditioning experiments. These conceptions and the relevant evidence were reviewed and analyzed by Rescorla and Solomon (1967). The most prominent hypothesis to account for the observed commonality is that each type of conditioning experiment may frequently, if not always, contain components of the other. Thus, as has been suggested by several writers (Shearn, 1961; Smith, 1954), heart-rate changes in experiments such as the present one may be strongly influenced by, if not entirely dependent upon, changes in skeletal behavior. However, the results from studies of cardiac conditioning under curare weigh strongly against the view that classical heart-rate conditioning

is dependent in any critical manner upon skeletal response (Black, 1965; Kimmel, 1967). Moreover, the results of recent studies of transfer from classical discriminative to instrumental discriminative learning suggest that dependence between the two response systems is of the opposite nature. For example, Trapold (1966) found that rats were immediately and markedly facilitated in learning an operant discrimination reversal if they were first given a period of training in which the S^D and S^A of the reversal learning were paired with reinforcement and non-reinforcement, respectively, and without instrumental response. In the context of the present experiment, such findings suggest that the observed similarity between classical and instrumental successive reversal learning arises from the presence of a determining classical conditioning component in the latter type of experiment.

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