THE AVERSIVE CONTROL OF AN OPERANT DISCRIMINATION^{1,2}

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Many investigators have shown that the bar-pressing behavior of the white rat may be brought under the control of environmental stimuli when on-going activity is maintained by food or water reward. Furthermore, Dinsmoor (1952a) has demonstrated that a discrimination may be formed by imposing a punishment contingency on a variable-interval base-line performance. Previously, Estes and Skinner (1941) found that the rate of response declines in the presence of a stimulus correlated with electric shock. Using this information, Dinsmoor (1952a) was able to suppress the rate of response by punishing bar presses in S^+ , while stable VI rates remained in S^0 where no shocks were presented.

Brady (1959) and Verhave (1959) studied the problem of whether or not an operant discrimination can be formed when the on-going behavior itself is maintained by aversive control. These investigators found that animals could discriminate an avoidance contingency of the kind studied extensively by Sidman (1953a) and others from a time out.

The present investigation was concerned with some of the conditions under which avoidance responding may be brought under stimulus control. Specifically, the questions raised were: 1) Can the rat learn to discriminate a condition in which an avoidance contingency is in effect from one in which it is not? 2) Can it discriminate avoidable from unavoidable shocks? and 3) Will the ability to discriminate vary as a function of the frequency of unavoidable shocks in S^+ ?

Interest in the problem of unavoidable shocks grew in part out of the results of a recent investigation by Sidman, Herrnstein, and Conrad (1957). They found that avoidance behavior in the rhesus monkey can be maintained for as long as 300 experimental hours after the avoidance contingency is removed and if occasional, unavoidable shocks are presented as infrequently as once every 10 minutes.

METHOD

Subjects

The subjects were six naive male albino rats, from 60 to 120 days old at the beginning of experimentation. They were housed in the departmental colony; food and water were available at all times except during experimental sessions.

Apparatus

The apparatus consisted of a single box, 5.875 inches wide, 10 inches long, and 6.75 inches high. The hinged top of the box was made of Plexiglas. The four walls, which functioned as one of six shock electrodes, were constructed of 0.125-inch aluminum. The other five electrodes were a grid floor, whose sections were of 0.625-inch, outside-diameter brass tubing spaced at 1.125 inches from center to center and running from one end of the box to the other (rather than crosswise as they are conventionally). Dinsmoor (1958) described the advantages of this arrangement.

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At one end of the apparatus, 3 inches from the grid floor, was an aluminum lever, 2.5 inches in length and 0.375 inch in diameter. This was fitted to a Switchcraft Lev-R type switch No. 3002 in the manner described by Verhave (1958). A pressure of from 5 to 10 grams applied to the lever operated a Potter and Brumfield KRP11D relay, mounted outside the cage, and thereby activated control apparatus. (The clearly audible click of this relay occurred only upon the initial depression of the lever, and could therefore serve to differentiate a press from a holding response.)

The experimental cage was housed in a light-proof and partially sound-proof box equipped with a blower and with a speaker connected to the output of a *Signa-Tone*³ audio-oscillator. The latter produced a tone of approximately 500 cycles per second at 87-decibel SPL, which served as a discriminative stimulus.

All experimental events were programmed automatically by relay and timing circuits. Shocks were delivered from the output of a variable transformer set at 30 volts in series with a 20:1 step-up transformer, through a 470,000-ohm fixed resistance. An electronic commutator alternated the polarities of the six electrodes in the experimental cage. On the average, the animal probably received from 1.0 to 1.3 milliamperes of shock on any trial.

Bar presses and shocks were recorded on magnetic impulse counters and a cumulative recorder; S^D and S^A cycles also appeared on the base-line marker of the cumulative record, and were timed electrically on running-time meters.

Procedure

Individual sessions were 4 hours long and were usually run on alternate days at approximately the same time. Experimentation was begun on young animals which received no prior handling or adaptation to the laboratory environment.

Phase I. All subjects were first given extensive training on an avoidance schedule. Shocks of 0.23-second duration were administered every 2 seconds unless the animal pressed the bar and thereby delayed the onset of the next shock by 20 seconds, RS 20 seconds, SS 2 seconds (Sidman, 1953b). Only the initial depression of the lever reset the timer controlling shock-onset; holding the bar down had no effect, so that each animal had to learn to discriminate a bar press from a bar hold to continue avoiding shock. The short SS interval was selected in an effort to obtain maximal rates of response for an RS interval of 20 seconds (Sidman, 1953b).

Phase II. Discrimination training was begun as follows. Twenty-minute periods of tone alternated regularly with 10-minute periods of no tone. Two control sessions (8 hours) were given to each animal to extinguish any unconditioned effects the tone might have had on the rate of avoidance response. During this time the Sidman schedule was in effect throughout the 4-hour sessions, so that the only difference in procedure from that of Phase I was the presence of tone and no-tone cycles.

Discrimination involved the removal of the avoidance contingency during the 10-minute no-tone intervals, S^A. The same avoidance schedule (RS 20 seconds, SS 2 seconds) was continued in the presence of the tone, S^D, for all animals. Conditions in S^A differed among subjects: Rats 3 and 5 were never given shocks in the absence of the tone during this phase of the experiment; Subjects 1 and 6 received unavoidable shocks of 0.23-second duration every 5 minutes (0.2 shock per minute); and Rats 2 and 4 were given shocks once every 2 minutes (0.5 shock per minute). This procedure was carried out for 30 4-hour experimental sessions.

³Manufactured by the Insuline Corporation of America, Long Island City, New York.

The remaining experimental procedure consisted of shifting the unavoidable shock contingencies in S^D in such a manner that each animal was given each condition of the independent variable, i.e., frequencies of 0, 0.2, and 0.5 shock per minute. In certain cases, however, it was reasoned that this was not necessary since the effects of the unavoidable shocks were sufficiently clear in fewer than the maximum number of experimental operations. The S^A shock timer was changed at different times for different animals, depending, at least in part, on the stability of the on-going behavior.

The formation of an operant discrimination involves the gradual extinction of bar pressing in S^A , when responses are never reinforced (Skinner, 1938), in the present case, by shock avoidance. Here, therefore, the rate of response should decline in the absence of the tone if a discrimination is to be formed; if no discriminatory behavior is observed, the rates or response in S^D and in S^A should be approximately equal.

In addition to rate, a measure of discriminability similar to one used by Dinsmoor (1952a) will also occasionally be employed. This is simply the ratio of rate of response in S^D divided by the sum of the rates in S^D and in S^A : $S^D/(S^D + S^A)$. The value of this fraction should vary from near 0.50, when discrimination is poor, to near 1.00, when discrimination is perfect, i.e., when there are no responses in S^A .

The experimenter's previous experience in operant discrimination learning, pilot work in this study, and the reports of a number of investigators have indicated that a "warm-up" period often occurs at the beginning of each experimental session during which the discrimination is considerably poorer than it was at the end of the previous session. Accordingly, data collected during the first hour of experimentation were ignored for the purposes of analysis. (Dinsmoor, 1952c) showed that this warm up is probably not due to forgetting. Intrasection curves show little decline in the ability of five rats to discriminate when re-tested 30 weeks after original test trials.)

RESULTS AND DISCUSSION

In Fig. 1 and 2, average rates of response in S^D and S^A are plotted against the first 30 sessions of discrimination training for two animals (Rats 3 and 5). In addition, the frequency of (avoidable) shocks in the presence of the tone is shown on separate coordinates beneath each record. It can readily be seen that the discrimination is formed by the extinction of responding in S^A ; but a decline in S^D rate and increase in the number of shocks received by the organism over sessions was not expected. The slopes of the cumulative records in Fig. 3 indicate that the over-all rate of bar pressing fell as a result of repeated exposure to the condition in which no shocks were given in S^A . The decline in rate is obviously a result of the frequent plateaus which occur in the no-tone condition.

Since the results of the other S s were substantially the same, it may be concluded that when the avoidance contingency is removed in the absence of the tone and no unavoidable shocks are given in S^A , all S s eventually learn to discriminate the condition during which the avoidance contingency is maintained from that in which it has been withdrawn. This is in agreement with other published findings (Brady, 1959; Verhave, 1959).

When the animals that have never been exposed to any kind of discrimination situation are given extensive training on a schedule in which unavoidable shocks are presented from time to time in the absence of the tone, discriminatory behavior is effectively inhibited. Animals 1 and 6 were given 30 sessions of discrimination training during which 0.23-second shocks were presented at a frequency of 0.20 shock per minute in S^A ; S s 2 and 4 received 30 sessions of unavoidable shocks at a frequency of 0.50 shock per minute. While there is a

Figure 1. The average rates of bar pressing in the presence of a tone, S^D , and in its absence, S^A , during the last 3 hours of the first 30 sessions of discrimination training are plotted against sessions for Animal 3 in Graph A. The frequency of unavoidable shocks in S^A is zero; the frequency of shocks in S^D for each session is shown in Graph B.

certain amount of variability in the results of these animals, the data do not indicate that discriminatory behavior develops under these conditions; the only exception may be Rat 4. In Fig. 4, rates of response in S^D and in S^A are plotted against sessions for Animals 4 and 2. The first of these S s exhibited the best discrimination of all rats shocked in S^A according to the discriminability-ratio measure which nevertheless attained a value of only 0.59 over the last five sessions of this phase of the experiment. In contrast to the records illustrated in Fig. 1 and 2, the rates are extremely variable from day to day. Bar pressing in the presence of the tone increases substantially; and while the rate of response may be somewhat lower in its absence, there is little indication of the extinction of S^A responding. The performance of Animal 2 was perhaps more typical. The S^D and S^A rates fail to diverge; again, responding is not extinguished in the absence of reinforcement, as was the case when the frequency of shocks in S^A was zero, nor does the S^D rate appear to decline.

The performance of Animal 1 illustrates an exceptionally low rate of responding in both tone-on and tone-off conditions; nevertheless, the rates are higher at the end of the 30 sessions of discrimination training than they were during control sessions. (The S^D rate was 7.10 responses per minute during the second control session and 8.72 responses per minute during Session 30. The corresponding S^A rates were 6.21 and 7.08 responses per minute.)

Two cumulative records drawn from early and late sessions of discrimination training of Animal 2 are shown in Fig. 5. If these curves are compared with those of Fig. 3, the control exercised by the presence of unavoidable shocks in S^A is demonstrated. The performance of Subject 2 shows neither plateaus in S^A nor an over-all decline in slope over sessions. Figure 6 shows, again, that the presentation of brief, unavoidable shocks in the absence of the discriminative stimulus can prevent the formation of a discrimination based on an avoidance contingency. Here, the absolute values of the rates of response in S^D and S^A are ignored in favor of their relative values as given by the discriminability ratio, $S^D/(S^D + S^A)$. The latter function rises over sessions for Animal 5, which is never shocked in the absence of the tone; but no such learning occurs for Animal 6, which was only shocked at a frequency of 0.20, or once every 5 minutes.

Thus far, the behavior of all six animals during their first 30 days of discrimination training has been analyzed in some detail. Changes in rates of response during S^D and S^A periods have been observed over sessions, while the frequency of unavoidable shocks has been held constant for a given subject; but the effect of manipulating this variable within a given animal is also of interest.

Figure 2. The average rates of bar pressing in the presence of a tone, S^D , and in its absence, S^A , during the last 3 hours of the first 30 sessions of discrimination training are plotted against sessions for Animal 5 in Graph A. The frequency of unavoidable shocks in S^A is zero; the frequency of shocks in S^D for each session is shown in Graph B.

Figure 3. Cumulative record of bar pressing for Animal 5 during the latter part of Sessions 4 and 28 of discrimination training. Upon the emission of 512 responses, the pen is reset. Shocks are indicated by vertical "pips." An avoidance contingency of RS 20 seconds, SS 2 seconds is in effect when a tone is on, S^D . The tone and the avoidance contingency are removed in S^A . Slopes of the curves are indicated by the coordinates at the upper left.

When unavoidable shocks are presented to rats that have previously been exposed to the discrimination problem with no shocks administered in S^A , the magnitude of the effect differs among S s and may be related to the animal's ability to discriminate.

Subject 3 was run on a schedule of 0.20 shock per minute in the absence of the tone, following the 30 sessions of no shocks in S^A already discussed and illustrated in Fig. 2. The rates of response in both S^D and S^A begin to rise by the 28th day of discrimination training. This continues during the first two sessions of the 0.20 unavoidable shock frequency; thereafter, the S^A rate declines until the 39th day, followed by considerable variability but poor discrimination although this animal was given 30 sessions under the 0.20 frequency. It should also be noted that Animal 3, which had a discriminability ratio of 0.78 at the end of the first 30 days of discrimination training, fell to a value of 0.58 during the last five sessions of conditioning under the 0.20 S^A frequency. This happened mainly because the S^A rate increased from 1.87 to 5.75 responses per minute. (A much smaller increase in S^D rate also occurred; but the change from 6.40 to 7.67 responses per minute in the presence of the tone is hardly enough to account for the decline in the discriminability ratio.)

In contrast, an unavoidable shock frequency of 0.50 shock per minute failed to permanently disrupt the ability of Animal 5 to discriminate the avoidance contingency. After initial increase in S^A rate, this subject exhibited excellent discriminatory behavior by the 35th day.

Subjects 1 and 4 were given 20 days of discrimination training without any unavoidable shocks, following 30 sessions of conditioning with 0.20 and 0.50 shock per minute in S^A , respectively. During this time, both animals learned to discriminate, but only reached ratios of 0.71 and 0.69 for the last five sessions of the zero shock condition.

When shifted to an unavoidable shock frequency of 0.50 shock per minute, the ability of Subject 1 to discriminate showed signs of weakening. Unfortunately, this animal contracted

middle-ear disease and had to be discarded after the 51st session of discrimination training. More data were available from Subject 4, which was given nine sessions on a schedule of 0.20 shock per minute in S^A following previous conditioning on first the 0.50 (30 sessions) and then the zero (20 sessions) frequencies. The discriminability ratio of this animal fell to 0.64 during the final five sessions of running, compared with the 0.69 value already reported during Sessions 15–20 of the zero shock in S^A condition (Sessions 45–50).

Figure 4. The average rates of bar pressing in the presence of a tone, S^D , and in its absence, S^A , during the last 3 hours of the first 30 sessions of discrimination training are plotted against sessions for Animals 4 and 2 in Graphs A and B, respectively. The frequency of unavoidable shocks in S^A is 0.50 shock per minute for both S s.

In Fig. 7, the asymptotic rates of response in both S^D and S^A are plotted against the frequency of unavoidable shocks in S^A for four S s. Shifting to a schedule in which unavoidable shocks are occasionally presented impairs the discrimination performance of Animals 3 and 4; no such lasting effect was observed with Subject 5. This is caused by a substantial rise in the S^A rate for which a much smaller rise in S^D rate fails to compensate. One difference among S s lies in the value of the discriminability ratio, $S^D/(S^D + S^A)$, at the end of the zero unavoidable shock frequency condition. This was much higher

Figure 5. Cumulative record of bar pressing for Animal 6 during the latter part of Sessions 4 and 28 of discrimination training. Upon the emission of 512 responses, the pen is reset. Shocks are indicated by vertical "pips." An avoidance contingency of RS 20 seconds, SS 2 seconds is in effect when a tone is on, S^D . Both the tone and the avoidance contingency are removed in S^A . Slopes of the curves are indicated by the coordinates at the upper left.

Figure 6. The ratio of average rate of response in S^D during the last 3 hours of the first 30 sessions of discrimination training divided by the average rate of response in S^D plus the average rate in S^A , or $S^D / (S^D + S^A)$, is plotted against sessions for Animals 5 and 6. The former received no shocks in the absence of the tone, while the latter was given a 0.23-second shock every 5 minutes.

Figure 7. The mean rates of bar pressing in the presence of a tone, S^D, and in its absence, S^A, calculated over the last 3 hours of the final five sessions of each experimental condition are plotted against the frequency of unavoidable shocks in S^A for Animals 1, 3, 4, and 5.

for Subject 5, whose discrimination was not impaired by the presentation of shocks in S^A, than for the other two Ss. (The ratio was equal to 0.91 for Subject 5, 0.78 for Subject 3, and 0.69 for Subject 4.) But whether or not the prior ability of these rats to discriminate influences the action of the independent variable is problematical, since the three animals were treated somewhat differently.

There is little, if any, difference between the two unavoidable shock frequencies (0.20 and 0.50 shock) in S^A to inhibit or impair the discriminatory behavior of the white rat. Two animals, 2 and 6, were given both frequencies before receiving any training without any shocks in the absence of the tone. Neither subject showed any discrimination under either shock frequency. Animal 2 was presented with 0.20 shock per minute for 20 sessions, following 30 sessions of training on the 0.50 value. The discriminability ratio increased from 0.51 to only 0.58 from the last five sessions of the higher, to the last five sessions of the lower, unavoidable shock frequency. Animal 6 showed no change in performance over 45 sessions when shifted from the 0.20 to the 0.50 frequency.

(The discriminability ratios were equal to 0.53 for both frequencies of unavoidable shocks in S^A for this subject.) To make sure that these animals could learn to discriminate the avoidance contingency under more favorable conditions, both subjects were given 15 sessions of discrimination training with no shocks in the absence of the tone. Discrimination occurred with these (as well as with all other) Ss under this condition. (The ratios calculated over the last five sessions of training reached 0.82 for Subject 2 and 0.75 for Subject 6.)

The asymptotic levels of performance under all conditions of the independent variable for Subjects 2 and 6 are indicated in Fig. 8, where rates of response in S^D and S^A are plotted against unavoidable shock frequency in the same manner as in Fig. 7. Once again, poor discrimination is caused by a substantial rise in the S^A rate when shocks are given in S^A for which a much smaller rise in S^D rate fails to compensate.

Figure 8. The mean rates of bar pressing in the presence of a tone, S^D , and in its absence, S^A , calculated over the last 3 hours of the final five sessions of each experimental condition are plotted against the frequency of unavoidable shocks in S^A for Animals 2 and 6.

Tables 1, 2, and 3 indicate, in terms of the discriminability-ratio measure, the ability of all six S s to discriminate during the last five sessions of every condition under which they were run. The function varies with the frequency of shocks in S^A , and attains a high value only in the absence of unavoidable shocks.

Table 1

Mean Rates of Response, Discriminability Ratios, and Frequency of Shocks in S^D during the Last Five Sessions in which the Frequency of Unavoidable Shocks in S^A Was Equal to Zero Shock per Minute

Animal	Mean Rate in S^D	Mean Rate in S^A	Mean Ratio $S^D/(S^D + S^A)$	Mean No. Shocks per min. in S^D
1	5.98	2.41	0.71	0.70
2	9.94	2.44	0.82	0.34
3	6.40	1.87	0.78	1.62
4	10.83	5.41	0.69	0.55
5	7.44	0.84	0.91	0.88
6	11.84	4.32	0.75	0.20

Table 2
Mean Rates of Response, Discriminability Ratios, and Frequency of Shocks in S^D during the Last Five Sessions in which the Frequency of Unavoidable Shocks in S^A Was Equal to 0.20 Shock per Minute

Animal	Mean Rate in S ^D	Mean Rate in S ^A	Mean Ratio S ^D /(S ^D + S ^A)	Mean No. Shocks per min. in S ^D
1	8.22	6.56	0.56	0.35
2	11.43	8.18	0.58	0.28
3	7.67	5.75	0.57	0.58
4	12.62	7.11	0.64	0.59
5	—	—	—	—*
6	15.69	14.29	0.53	0.19

*Animal 5 was not run on this unavoidable shock frequency.

Table 3
Mean Rates of Response, Discriminability Ratios, and Frequency of Shocks in S^D during the Last Five Sessions in which the Frequency of Unavoidable Shocks in S^A Was Equal to 0.50 Shock per Minute

Animal	Mean Rate in S ^D	Mean Rate in S ^A	Mean Ratio S ^D /(S ^D + S ^A)	Mean No. Shocks per min. in S ^D
1	—	—	—	—*
2	11.53	11.03	0.51	0.39
3	—	—	—	—**
4	15.61	11.08	0.59	0.30
5	8.17	1.30	0.86	0.82
6	10.66	9.32	0.53	0.38

*Subject 1 contracted middle-ear disease and was discarded one day after the beginning of training on this unavoidable shock frequency.

**Animal 3 was not run on this unavoidable shock frequency.

Because a white rat can learn such a discrimination, the field of operant discrimination learning can be extended to situations where on-going behavior is maintained by aversive control; it also confirms findings of Verhave and Brady. An interesting secondary result of removing the avoidance schedule in S^A (and not presenting any unavoidable shocks) is that the discrimination is formed by the extinction of bar pressing in the absence of reinforcement by shock avoidance although the rate during S^D declines at the same time. This does not seem to be the case during prolonged exposure to more orthodox discrimination problems (Dinsmoor, 1951; Herrick, Myers, & Korotkin, 1959; Smith & Hoy, 1954).

Perhaps the most dramatic effect observed during this investigation is the ability of unavoidable shocks to prevent the development of a discrimination when presented as infrequently as once every 5 minutes to animals that have had extensive training on an avoidance

procedure. Because the extinction of responding in the absence of the discriminative stimulus is effectively inhibited, no discrimination develops although the rate increases over sessions in S^D when shocks are presented in S^A . The ability of unavoidable shocks to increase the rate of avoidance responding has already been demonstrated in monkeys (Sidman, Herrnstein, & Conrad, 1957), but not in a discrimination situation.

SUMMARY AND CONCLUSIONS

This investigation was concerned with some properties of an operant discrimination based on aversive control. More specifically, the question of whether or not an organism can learn to discriminate a situation in which an avoidance contingency is in effect, from one in which it has been removed, was investigated as a function of the frequency of unavoidable shocks presented from time to time in S^A .

Six white rats were given extensive training on a schedule in which brief electric shocks of high intensity were presented every 2 seconds unless an animal pressed a bar and thereby delayed the occurrence of the next shock by 20 seconds. The discrimination procedure was introduced by continuing this contingency in the presence of a tone, S^D , but removing it in its absence, S^A . Three experimental conditions prevailed during S^A , i.e., no shocks, unavoidable shocks of brief duration presented once every 5 minutes (0.20 shock per minute), and unavoidable shocks presented once every 2 minutes (0.50 shock per minute). Rates of response in the presence and in the absence of the discriminative stimulus, as well as a measure of discriminability, were determined as a function of this variable; changes in behavior in time were also noted.

Analysis of the various conditions of discrimination learning for each of the six animals yielded the following results:

1. When the avoidance contingency is removed in the absence of the discriminative stimulus and no unavoidable shocks are presented, Ss learn to discriminate the condition during which the avoidable schedule is in effect. This discrimination is formed by gradual extinction of bar pressing in the absence of the tone; but an observed decline in S^D rate is at variance with results obtained in discrimination situations involving food reward in the presence of the positive stimulus.

2. When animals that have never been exposed to any kind of discrimination situation are given extensive training on a schedule in which unavoidable shocks are presented from time to time in the absence of the discriminative stimulus, discriminatory behavior is effectively inhibited. Rates of response in S^D and in S^A fail to diverge, and the unavoidable shocks increase bar-pressing activity not only in S^A , but also in S^D .

3. When unavoidable shocks are presented to rats that have previously been exposed to the discrimination problem with no shocks administered in S^A , the effect differs among Ss . Rates of response in the absence of the tone increase sufficiently more than did S^D rates in the case of three Ss , so that their discrimination was considerably impaired when unavoidable shocks were presented as seldom as once every 5 minutes in S^A . One subject learned to cease responding in the presence of a 0.50 unavoidable shock frequency.

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