SIGNAL FUNCTIONS IN DISCRIMINATED AVOIDANCE BEHAVIOR¹

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Four rats were trained to lever press under a discriminated avoidance/escape schedule in which separately signalled safe and warning periods were 100 sec and 32 sec respectively. The auditory and not the visual component of the compound warning signal became associated with the discriminative control of lever pressing. Avoidance behavior also came under temporal control, in that the probability of lever pressing increased as the warning period progressed. Timing began with the onset of the warning signal rather than the offset of the safe signal. However, after the warning signal had been progressively eliminated, timing began with the offset of the safe signal. When neither signal was normally available, the temporal distribution of avoidance behavior changed markedly. Drifts in the temporal distribution of lever pressing occurred throughout the study; these were manipulated for two animals.

In the conventional discriminated avoidance procedure, a safe period, during which behavior is without scheduled consequence, is followed by a warning period during which emission of behavior selected arbitrarily by the experimenter, such as pressing a lever or leaving a certain area, reinstates the safe period. If the selected behavior is not emitted during the warning period, a shock period follows and continues until the behavior is emitted, whereupon the safe period is reintroduced. If the selected behavior is lever depression, a lever press during the warning period avoids shock and a lever press during the shock period escapes shock. One environmental state, the safe signal, is correlated with the safe period, and another state, the warning signal, is correlated with the warning period. The warning signal usually continues through the shock period.

Many experimenters have shown that such a procedure maintains avoidance behavior. Hoffman (1966), Morgan (1968), and Hurwitz and Dillow (1969) have reviewed much of the literature. The maintenance of this kind of avoidance behavior has been attributed to various sources within and without the organism. Sources within the animal have included escape from "fear" (Rescorla and Solomon, 1967; Miller, 1969) and escape from "conditioned aversive temporal stimuli" (Anger, 1963). Other sources that have been implicated are removal of the warning signal (Schoenfeld, 1950), presentation of the safe signal (Grossen and Bolles, 1968; Rescorla, 1969), punishment of other behavior (Dinsmoor, 1954) and various attributes of the avoidance of shock, such as reduction in shock frequency (Herrnstein, 1969) and postponement of shock (Hineline, 1969). As well as considering the reinforcing functions of the environmental states, it is possible also to consider their discriminative functions (Keehn, 1959), hence the use of the epithet "signal" in this paper.

A preliminary study confirmed earlier research that has shown that discriminated avoidance behavior is acquired most rapidly when electric shock is discontinuous and of low intensity (D'Amato and Fazzaro, 1966), when there is prior pairing of the warning signal and shock (Zielinski and Soltysik, 1964), and when an explicit shaping procedure is used (Keehn and Webster, 1968; Lockard, 1969). The main

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difference between shaping and exposing the animal immediately to the final schedule lies in the treatment of approximations to the specified operant. Approximations are systematically reinforced in the case of shaping, and often punished by shock delivery in the more commonly used techniques. In the present study, reinforcement comprised shock-free removal of a warning signal that had previously been paired with shock. Other considerations in the training and maintenance of discriminated avoidance behavior are lever holding and the duration of the safe and warning periods. Lever holding is a frequent feature when a lever press is the required operant (Hoffman, 1966) and its elimination leads to the earlier appearance of efficient avoidance behavior (Forgione, 1970). It was found that lever holding did not occur when the safe and warning periods were relatively long, a point confirmed by Walsh and Keehn (1969).

The resulting training procedure and maintenance schedule were such that an animal received very few shocks. The delivery of shock has immediate and peculiar effects on behavior. It gives rise to respondent behavior that may be incompatible with the operant behavior under examination (Ulrich, 1967; Bolles and McGillis, 1968), it may reinforce the behavior of an animal that has a history of shock avoidance (Kelleher and Morse, 1968), and it may also punish such behavior (Feldman and Bremner, 1963). To gain a clear understanding of the effect of avoidance contingencies, it may be necessary to minimize the contaminating effects of presenting the aversive event. Procedures such as those of Sidman (1953) and Herrnstein and Hineline (1966), which typically give rise to shock rates of from 3 to 10 per min (Herrnstein, 1969), may tell more about contingencies of shock presentation than about contingencies of shock avoidance, inasmuch as the two are distinguishable.

The first aim of the present study was to assess the extent of the discriminative control over avoidance behavior that was engendered by the training procedure discussed above.

The second aim was to note which, if either, of the auditory and visual components of the compound warning signal was most associated with the discriminative control of the avoidance behavior. Previous work suggested that the auditory and not the visual component might gain control (Sidman, 1955; Field and Boren,

1963; Keehn, 1969). However, comparisons of control by the two types of signal over the positively reinforced behavior of rats have shown that visual control predominates at normal intensities (e.g., the review by Munn, 1950; Gilbert and Croskerry, 1969). Compared with the values used by Gilbert and Croskerry, the intensity differences between the signals used in the present study were such as to reduce the chance that auditory control would predominate. Specifically, the sound intensity difference was never more than 6 db in the present study, whereas it was 10 db in that study; the signal lamp was above the lever and rated at 10 w in the present study, whereas it was at the other side of the chamber and rated at 2.5 w in the earlier study.

The third aim was to examine the effect of removing the safe and warning signals, at first separately and then together, an object being to assess the relative contributions of each as a signal for emitting or not emitting avoidance behavior.

An incidental, but pervading result of the present study was a gradual drift in the temporal characteristics of avoidance behavior as the study progressed, similar to what has been called an "avoidance decrement" by Anderson and Nakamura (1964). This drift was investigated and remedied in two of the participating animals.

METHOD

Subjects

Four male hooded rats, numbered 14, 15, 407 and 1104, came originally from the stock maintained by the Rowett Institute, Aberdeen. They were experimentally naive. Each weighed about 240 g at the beginning of the study and was approximately 110 days old. Free access to food and water was allowed except during the daily experimental sessions, which were usually of about 110 min duration.

Apparatus

A standard Grason-Stadler two-lever rat chamber was used, with the food tray opening covered. The chamber and its enclosing chest were in a cubicle in the room containing the controlling and recording equipment. Shocks were provided either by a Grason-Stadler generator/scrambler (Rats 15 and 407, later part of the study, as indicated below) or by drop-

ping the local main supply (240 v, 50 Hz) across a resistor in series with a Foringer relay scrambler (Rats 14 and 1104; and Rats 15 and 407, earlier part of study). Scheduling was achieved using transistorized modules, supplemented by a tape reader during test sessions. Recording facilities comprised a cumulative recorder, electromagnetic counters, and a Grason-Stadler printout counter. Sound signals were provided by a Foringer click generator set at approximately 4.0 Hz and a Foringer white-noise generator. The background noise inside the chamber averaged 78 db re 20 N/mm² according to the meter used. The central green stimulus light was on continuously during sessions; the standard houselight was not used. The 10-w white light by the left-hand lever position was used as a signal. Except during the first two sessions, a standard lever was available in the left-hand position. Operation of this lever, which required a force of approximately 0.1 N, could lead to avoidance of shock.

Procedure

Sessions 1 to 7: training. After two weeks of daily gentling, each rat was placed in the leverless chamber for 20 min with the click on continuously, its intensity such as to raise the ambient noise level from 78 db to 84 db. On the second day, the click (safe signal) and the white noise plus light (warning signal) alternated, each being available for 10 periods of 30 sec: the warning signal was followed by an unavoidable 0.5-sec, 0.4-mA shock. The electric current intensities given here are those estimated by assuming that a rat's resistance is 150 k Ω . When the white noise was on it raised the average ambient noise intensity by 4 db to 82 db.

The lever was introduced on the third day and avoidance behavior was trained by making removal of the warning signal and restitution of the safe signal dependent upon successive approximations to lever pressing. During this shaping procedure, the duration of the warning signal was occasionally extended beyond 30 sec to avoid punishment of early approximations to lever pressing. Once a few lever presses had occurred, the schedule was changed so that a train of 0.2-mA shocks, 0.5 sec apart and each of 0.5-sec duration, was delivered when the warning signal had been on for 30 sec; the warning signal continued throughout the shock train. A lever press during the warn-

ing signal terminated that signal, terminated the shock train if it had begun, and reinstated the safe signal. Presses on the lever during the safe signal had no scheduled consequence at any phase of the study. On the third day, session durations were approximately 150 min each; subsequently all sessions terminated at the end of 60 cycles. Each cycle began with the onset of the safe period and continued until the offset of either the warning period or the shock period.

For Sessions 4 through 7, the procedure remained as at the end of the third session except that the safe period was extended to 83 sec per cycle. Subsequently, the duration of the safe period and the maximum duration of the warning period were 100 sec and 32 sec respectively, unless otherwise indicated below: this constituted the regular cycle, and a regular, or baseline, session consisted of 60 such cycles, of which only the last 50 cycles were included in analyses.

Sessions 18, 20, and 22: test for control by the components of the warning signal. Control was assessed by a series of test cycles in each of which one of the components of the warning signal, white noise or stimulus light, was brought on 20 sec early. The last 50 cycles of these three sessions comprised 30 regular cycles and 20 test cycles, irregularly ordered. For a test cycle, the safe period duration was reduced from 100 sec to 80 sec, and the maximum duration of the warning signal was increased from 32 sec to 52 sec. Only one component of the warning signal was on for the first 20 sec of the warning period; both were subsequently available unless a lever press had already occurred during that warning period.

Sessions 25 to 38: estimation of control by the warning signal. From Session 25 onwards, the light was no longer used as a component of the warning signal. Occasional omission of the white noise warning signal during Session 25 confirmed that the animals were under the control of the warning signal rather than the offset of the safe signal. The intensity of the warning signal was then gradually reduced to zero over nine sessions. When avoidance behavior had been maintained without the warning signal, two sessions without the warning signal were alternated with regular sessions. Avoidance behavior was not affected by reduction of warning signal intensity to the level at which it was still clearly audible to the experimenter

but did not raise the average ambient noise intensity above the background level of 78 db, according to the meter. Subsequently, the regular intensity of the white-noise warning signal was set at this value, or such that it raised the noise level by 1 db.

Sessions 50, 52, and 54: assessment of avoidance decrement (Rat 407 only). The last 50 cycles of these sessions comprised 20 test cycles, during which the safe period duration was reduced to 80 sec and the maximum warning period duration was increased to 52 sec, and 30 regular cycles. Thereafter, the shock intensity for this rat was increased by stages to 0.6 mA. For comparison, the shock intensity was increased also for Rat 15, an animal that had not exhibited a substantial avoidance decrement. The Grason-Stadler generator/scrambler was used for the higher intensities.

Sessions 64 to 78: estimation of control by safe signal. Occasional omission of the safe signal during Session 64 had no effect on avoidance behavior. Nevertheless, the procedure used for estimating control by the warning signal (Sessions 25 to 38) was repeated. The safe signal intensity was reduced to zero over nine sessions, and then three sessions without the safe signal were alternated with regular sessions.

Sessions 82 to 86: omission of both signals. Neither the safe signal nor the warning signal was normally available during these five sessions, although the temporal features of the schedule remained those of regular sessions. (Actually, during this phase of the study, the appropriate signal was available for 5 sec following a press on a second lever. Rates of pressing the second lever were unaffected by this dependency and they remained much lower than the rates of pressing the avoidance lever. Thus, the signals were presented infrequently: it was concluded that in effect they were continuously absent.) Finally, baseline sessions were scheduled.

RESULTS

Training, and Test for Control by Components of the Warning Signal

Each rat pressed the lever during Session 3, which was when it was introduced. Performance from the fourth to the thirteenth sessions was characterized by a decline in lever holding, by a decline in the rates of lever pressing, by

an increase in the proportion of shocks avoided, and by an increase in the modal latency of lever presses to the onset of the warning signal. Failures to avoid shock were distributed fairly evenly within sessions, although rates of lever pressing tended to be highest at the beginning of sessions: there was no evidence of "warm-up" (Hoffman, Fleshler, and Chorney, 1961) at this or any other stage of the study.

Performance during Sessions 14 through 17 is represented by Row A of Fig. 1, each histogram of which is based on 200 cycles, the last 50 of each session. Nearly all shocks were avoided at this stage and most lever presses occurred during the warning signal. Rates of lever pressing just prior to the warning signal were little different from the average rates during the safe signal. Modal values of latencies of lever pressing to the onset of the warning signal tended to be associated with the second 4 sec of the warning period. It should be noted that a decline in the relative frequency of lever pressing as the warning period progressed, as shown in Row A of Fig. 1 and in other places, does not necessarily indicate a decline in the probability of lever pressing. An estimate of probability can be gained by dividing the actual number of lever presses by the potential number of lever presses. Because each press in the warning period terminated the warning period there were more opportunities to lever press near the beginning of the period than near the end. A statistic that takes the number of opportunities into account has been devised by Anger (1963), and a version of that statistic is used later in this analysis.

Data from cycles in which the auditory or visual component of the warning signal was brought on 20 sec early, 30 cycles in each case, are given in Rows B and C respectively of Fig. 1. The distribution of lever presses was shifted by 20 sec in the case of premature onset of the auditory component and not in the case of premature onset of the visual component. A reasonable conclusion from these data is that the auditory component was associated with the control of lever pressing and the visual component was not, except perhaps slightly in the case of Rat 14. It is clear from Row C of Fig. 1 that avoidance behavior was occasioned by the presence of the white-noise warning signal, rather than by the absence of the click safe signal.

Fig. 1. Relative frequency of lever presses in each of 15 class intervals of the experimental cycle. Each histogram represents the performance of one rat for the sessions or parts of sessions indicated. The left-most stippled bar in each case refers to the first 80 sec of the cycle and shows the *average* relative frequency per 4-sec interval within that 80 sec. The remaining class intervals are of 4 sec each except for the right-most hatched bar, which includes all lever presses that occurred more than 132 sec after the beginning of the cycle. Both stippled and open bars refer to lever presses during the safe period: these presses did not terminate the cycle. Filled bars refer to lever presses during the warning period. Hatched bars refer to lever presses that occurred after the beginning of the shock train. The percentage of the cycles represented for which shock was avoided is given at the right of each histogram.

Baseline performance during the same three sessions is represented by Row D of Fig. 1, each histogram of which is based on 90 cycles. Comparison of this performance with that during Sessions 14 to 17, represented in the top row of

Fig. 1, suggests that the distribution of lever presses in the warning period had shifted away from the onset of the warning signal, the shift being most marked in the case of Rat 407 and least marked in the case of Rat 14.

Observation of the rats' behavior at about Session 20 revealed what may be best described as a casual demeanor. More often than not a rat was lying on the grid floor throughout most of the safe period, beginning to rise slowly and press the lever only when the warning signal had been on for 5 sec or more. Occasionally, ears were observed to twitch at the onset of the warning signal. Latencies of lever presses to the onset of the warning signal appeared to be related to what an animal was doing when the signal came on. For example, latencies were usually long (> 20 sec) when an animal was grooming, and short (< 4 sec) when an animal was exploring the area of the lever.

Progressive elimination of the warning signal. Occasional omission of the warning signal during Session 25 invariably resulted in failure to avoid shock. However, after the progressive reduction of warning signal intensity, between Sessions 25 and 33, omission of the warning signal had little apparent effect on avoidance behavior, as shown by the Rows E and F of Fig. 2. With the exception of Rat 407, whose avoidance decrement had become more obvious, the distributions in Row E of Fig. 2 and Row D of Fig. 1 are very similar, suggesting that the progressive elimination of the warning signal did not affect baseline performance when the warning signal was present. Comparisons between Rows E and F of Fig. 2 show that more lever presses occurred during the safe signal, and that shock was avoided less often, in the sessions when the warning signal was absent (Row F) than in the adjacent sessions when it was present (Row E).

Progressive elimination of the safe signal. Occasional omission of the safe signal during Session 64 had no obvious effect on behavior. Thus it was to be expected that progressive reduction of the safe signal intensity would have little effect. When, after this procedure, sessions with and without the safe signal were alternated, performances during the two kinds of session were similar for the most part, except in the case of Rat 14, as can be seen in Rows I and J of Fig. 2. For Rat 14, the reintroduction of the safe signal at full intensity appeared to affect avoidance behavior in the intervening sessions when the safe signal was absent, such that fewer shocks were avoided. In the other three rats, there was a slight tendency for latencies of lever presses to the onset of the warning signal to be shorter during sessions

when the signal was absent than during sessions when it was present. Omission of the safe signal appeared to have no consistent effect upon lever pressing in the safe period.

Omission of both signals. When neither signal was normally present, the total number of lever presses per session increased by approximately four times in the case of each rat. All of this increase, of necessity, occurred in the safe period, and thus the relative frequency of presses was greater in the safe period and less in the warning period when compared with baseline conditions. These changes in relative frequencies can be seen by comparing Row K of Fig. 2 with Row I. The histograms in Row K show also that the proportions of lever presses at the end of the safe period and at the beginning of the warning period were approximately the same: the decline in relative frequency as the warning period progressed reflected the fewer opportunities to press at longer intervals. Rats 15 and 407 avoided about the same proportion of shocks without the signals as during regular sessions (compare Rows K and I). The data suggest that, in the absence of signals, these animals, which were now receiving a shock intensity of 0.6 mA, pressed the lever at a constant rate sufficient to avoid as many shocks as before. The other two animals, which continued to receive the lower-intensity shock, also pressed at a fairly constant rate but one that was not sufficient to maintain the same level of avoidance.

Row L of Fig. 2 is based on data from the two baseline sessions that followed the sessions without either stimulus. The performance of Rats 15 and 407, which received the higher shock intensity, was now very similar to their performances soon after original training, as shown in Row A of Fig. 1. On the other hand, the performance of Rat 14 and 1104 had drifted further; they were avoiding fewer shocks than in previous baseline sessions, and Rat 1104 tended to press later in the cycle. It is clear that removing both signals did not prevent them from reassuming control when they were reintroduced.

Assessment of avoidance decrement and increase in shock intensity. By Session 50 there had been a noticeable change in the distributions of avoidance behavior. All rats were pressing less in the safe signal, later in the warning signal, and avoiding fewer shocks than before. The drift was particularly marked for

Fig. 2. Relative frequency of lever presses in each of 15 class intervals of the experimental cycle. Each histogram represents the performance of one rat for the sessions or parts of sessions indicated. The left-most stippled bar in each case refers to the first 80 sec of the cycle and shows the *average* relative frequency per 4-sec interval within that 80 sec. The remaining class intervals are of 4 sec each except for the right-most hatched bar, which includes all lever presses that occurred more than 132 sec after the beginning of the cycle. Both stippled and open bars refer to lever presses during the safe period: these presses did not terminate the cycle. Filled bars refer to lever presses during the warning period. Hatched bars refer to lever presses that occurred after the beginning of the shock train. The percentage of the cycles represented for which shock was avoided is given at the right of each histogram.

Rat 407; its extent can be gauged by comparing Histograms A and G at the top of Fig. 3. Avoidance behavior remained under the control of the change from safe signal to warning signal. This can be seen by comparing Histograms G and H in the middle of Fig. 3: when the warning signal was brought on 20 sec early, the distribution shifted appropriately.

The change from safe to warning signal was initiating temporal control over avoidance behavior, but this is not apparent from the histograms because the relative frequencies do not take into account the reduction in opportunities to lever press in the warning period as time passed. A version of the interresponse time per opportunity (IRT/op) statistic (Anger, 1963) can give an estimate of the actual probability of a lever press within each interval of the warning period, also known as the conditional probability. For the present data, an estimate of the probability of a lever press in each 4-sec interval of the warning period was made by dividing the actual number of presses in that interval by the potential number. The potential number of lever presses was calculated as the sum of actual number of presses in the interval under consideration and in subsequent intervals. Figure 4 gives estimates of probability values for the regular and test cycles respectively of Sessions 50, 52, and 54. Evidence for temporal control over avoidance behavior is provided by the initial parallel rise in the two probability curves of Fig. 4 and, more particularly, by the peak in the curve for test cycles at the seventh interval of the warning period. A rising curve indicates that the probability of a lever press increased in successive portions of the warning period. As there was no exteroceptive stimulus correlated with the passing of the warning period, it is a reasonable assumption that the behavior was under control of the passage of time since the change from safe signal to warning signal.

The effect of introducing a higher shock intensity was immediate. During the last 50 cycles of Session 57 (0.2-mA shock) only one of the 50 presses in the warning signal occurred during the first 16 sec of the warning period. In Session 58 (0.4-mA shock) there were 26 such presses; in Session 59 (0.2-mA shock) there was again one such press. During the next three sessions, a drift occurred even with the 0.4-mA shock; during the last 50 cycles of Session 62, only 18 presses occurred during the

Fig. 3. Relative frequency of lever presses in each of 15 class intervals of the experimental cycle. Each histogram represents the performance of Rat 407 for the sessions or parts of sessions indicated. The left-most stippled bar in each case refers to the first 80 sec of the cycle and shows the *average* relative frequency per 4-sec interval within that 80 sec. The remaining class intervals are of 4 sec each except for the right-most hatched bar, which includes all lever presses that occurred more than 132 sec after the beginning of the cycle. Both stippled and open bars refer to lever presses during the safe period: these presses did not terminate the cycle. Filled bars refer to lever presses during the warning period. Hatched bars refer to lever presses that occurred after the beginning of the shock train. The percentage of the cycles represented for which shock was avoided is given at the right of each histogram.

first 16 sec of the warning period. Shock intensity was then increased to and subsequently maintained at 0.6 mA, when performance stabilized with about half of the presses in the warning period occurring during the first 16 sec of that period, as represented in Histogram I at the bottom of Fig. 3. Other consequences of the increase in shock intensity, including the effects upon Rat 15, have been discussed above.

Temporal control. Control by the passage of time over behavior in the warning period has already been implicated in the particular case of Rat 407 when that rat was exhibiting an extreme avoidance decrement. Temporal control during the warning period was a general feature of the avoidance behavior of all rats. Figure 5 shows conditional probability estimates derived from the baseline session data that were presented in Fig. 1 and 2. In every curve of Fig. 5, the second point is higher than the first point, indicating that, given the opportunity, a press was more likely during the second 4 sec of the warning period than during the first 4 sec. In 15 of 19 cases, the third point is higher than the second. The curves generally rose first and then fell, showing that at the beginning of the warning

Fig. 4. Probability of a lever press by Rat 407 in each of the 4-sec intervals of the warning period arranged in order during Sessions 50, 52, and 54, when the warning period duration was 32 sec (filled circles) and when it was 52 sec (open circles). Each estimate was based on more than 40 opportunities for a lever press.

period a lever press became more likely as time passed, and that towards the end of the period it became less likely as time passed. Both a rising and a falling curve can be evidence of temporal control; each case suggests

Fig. 5. Probability of a lever press in each of the eight 4-sec intervals of the warning period. Each curve is based on data given in Fig. 1 or Fig. 2 and represents baseline performance at various stages of the study as follows: A—Sessions 14 to 17; D—parts of Sessions 18, 20, and 22; E—Sessions 36 and 38; I—Sessions 74, 76, and 78; L—Sessions 87 and 88. The curves are arranged vertically to conserve space, but the shapes are the same as if each curve had its own axis. The scale at the left is valid for each curve. Probabilities were not estimated when there were fewer than 13 opportunities for a lever press.

that the probability was changing lawfully with the passage of time.

Figure 5 also gives a further illustration of the development of the avoidance decrement. The probability curves show a tendency to peak later as the study progressed, indicating that lever presses were occurring later in the warning period. This tendency is particularly evident in the data from Rats 14 and 1104, which received no change in shock intensity during the study.

Anger (1963) and Hineline and Herrnstein (1970) demonstrated that conditional probability estimations may be distorted by inhomogeneity in the data on which they are based. Scattergrams of the kind presented by Hineline and Herrnstein were hand-plotted from the data on which Fig. 5 is based. These plots failed to reveal the inhomogeneity that was characteristic of the data from the animals under their discrete-trial procedure. However, the sessions here comprised fewer cycles (effectively 50 as opposed to 300 in the study by Hineline and Herrnstein), allowing much less opportunity for within session inhomogeneity to occur.

DISCUSSION

Stimulus Control

Shortly after training, the exteroceptive control of lever pressing had been assumed almost entirely by the white-noise component of the warning signal. The finding that auditory control predominated over visual control is consistent with a number of studies of avoidance behavior in which the defined operant has been a lever press (*e.g.*, Sidman, 1955; Field and Boren, 1963; Keehn, 1969). When other kinds of procedure have been used to investigate avoidance behavior, visual control has been stronger, as when a two-way shuttle-box has been used (Freedman and Callahan, 1968) and its lever-pressing analog, the double-discrimination procedure (Keehn, 1969). Studies involving positive reinforcement have also found visual control to be more persistent (*e.g.*, Gilbert and Croskerry, 1969). It is arguable that auditory control is more likely in the kind of experiment reported here because an auditory signal allows continued control while other behavior occurs, whereas a visual signal might keep the animal looking at and possibly pressing the lever. The studies in which visual

signals were found to be more important required subjects to maintain relatively sustained orientation towards a particular location for maximum efficiency in avoiding shocks or gaining reinforcement. A similar account of differences in the effectiveness of warning signals has been offered by Bolles, Hargreve, and Grossen (1970). Obviously, considerations of relative discriminability enter into inter-modal comparisons of the effectiveness of signals: both species and parameter variables should be taken into account. Nevertheless, the evidence suggests that a simple statement about "attending hierarchies" (Baron, 1965) of modalities is inaccurate, and that the behavior of organisms is controlled by whichever features of the environment are made most appropriate by the ongoing reinforcement dependencies.

Avoidance behavior was also under control of the passage of time, in that pressing tended to occur later than at the beginning of the warning period. Ulrich, Holz, and Azrin (1964) found that most avoidance behavior occurred very shortly after the onset of the warning period, but there are many findings consistent with the present data (Sidman, 1966; Keehn, 1967; Stretch and Skinner, 1967). The extremely high shock intensity (5 mA) employed by Ulrich *et al.* may account for their discrepant result, although such an account may not be necessary for Hineline and Herrnstein (1970) demonstrated that both kinds of distribution may occur at a lower shock intensity (0.8 mA).

Shortly after training, temporal control was initiated by the onset of the warning signal, rather than by the offset of the safe signal. When the warning signal was faded out, temporal control was essentially unaffected, confirming Hineline's and Herrnstein's (1970) finding that the actual presence of a signal, as opposed to its absence, is unimportant for timing. Temporal control was now initiated either by the offset of the safe signal or by the "onset of the absence" of that signal: there was no way of choosing between these alternatives. Animals received more shocks without the warning signal, consistent with the results of Hurwitz and Dillow (1969) that a brief signal at the beginning of the warning period is less effective in maintaining avoidance behavior than a persistent signal. The warning signal may have promoted efficient avoidance with-

out being essential for timing, thus supporting the suggestion of Hineline and Herrnstein (1970) that the two processes are not necessarily related.

Removal of either safe or warning signal affected avoidance behavior very little or not at all, whereas removal of both signals produced quite a different distribution of this behavior in time. The last result might have been expected: with both signals gone there remained no indication of the beginning of the warning period except the passage of 100 sec, and there had been no evidence of temporal control during the safe period.

Avoidance Decrement

As the study progressed, the modal occurrence of the avoidance behavior of all animals drifted away from the onset of the warning period and more shocks were delivered. Similar drifts in performance have been noticed within long sessions (Boren, 1960) and over many sessions (Anderson and Nakamura, 1964). Such a drift is equivalent to a decline in the rate of emission of avoidance behavior, a point substantiated by the fact that, in the present study, an increase in the proportion of shocks received was usually accompanied by a decline in the rate of lever pressing in the safety signal.

Two kinds of account may be given of the drift in performance. One account points to the reinforcement schedule: lever presses late in the warning period produced a potentially lower rate of shock delivery than earlier lever presses. An objection to this account is that potential shocks are less important than actual shocks (Hake, 1968) and the drift was associated with an increase rather than a decrease in the actual rate of shock delivery. Furthermore, Hineline and Herrnstein (1970) found that timing occurred under a schedule in which pressing the lever late in the warning period did not reduce the potential rate of shock delivery.

The other account assumes both that "animals may tend to respond with long latencies or low rates so long as these produce no drastic consequences, just as they tend toward the least effortful responding that reinforcement contingencies permit" (Hineline and Herrnstein, 1970, p. 125), and that shock avoidance became a less effective reinforcer as the study progressed. Perhaps receiving a 0.2-mA shock

was initially a "drastic consequence" but became insufficient to prevent "least effortful responding", whereas a 0.6-mA shock was sufficient. It is not clear, however, that doing something immediately after a signal occurs is more effortful than waiting and doing it 16 sec later. A decline in the effectiveness of aversive events has been noted in another context, that of "recovery during punishment" (Azrin and Holz, 1966). A possible source of such a decline in effectiveness might lie in the operant behavior of the organism. Rats have been observed to increase their sensitivity to constant electric current by increasing their resistance (Green, 1958), and to reduce sensitivity by lying on their backs (Azrin and Holz, 1966). It is conceivable that a less dramatic reduction could be achieved, possibly as the result of appropriate disposition of the peripheral vasomotor system (Miller, 1969).

REFERENCES

- Anderson, N. H. and Nakamura, C. Y. Avoidance decrement in avoidance conditioning. *Journal of Comparative and Physiological Psychology*, 1964, 57, 196-204.
- Anger, D. The role of temporal discriminations in the reinforcement of Sidman avoidance behavior. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 477-506.
- Azrin, N. H. and Holz, W. C. Punishment. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 380-447.
- Baron, M. R. The stimulus, stimulus control, and stimulus generalization. In D. I. Mostofsky (Ed.), *Stimulus generalization*. Stanford: Stanford University Press, 1965. Pp. 62-71.
- Bolles, R. C., Hargrove, G. E., and Grossen, N. E. Avoidance learning as a function of CS quality and CS termination on escape trials. *Psychological Reports*, 1970, 26, 27-32.
- Bolles, R. C. and McGillis, D. B. The non-operant nature of the bar-press escape response. *Psychonomic Science*, 1968, 11, 261-262.
- Boren, J. J. Decrement in avoidance performance during prolonged avoidance sessions. *Journal of the Experimental Analysis of Behavior*, 1960, 3, 201-206.
- D'Amato, M. R. and Fazzaro, J. Discriminated lever-press avoidance learning as a function of type and intensity of shock. *Journal of Comparative and Physiological Psychology*, 1966, 61, 313-315.
- Dinsmoor, J. A. Punishment: I. The avoidance hypothesis. *Psychological Review*, 1954, 61, 34-46.
- Feldman, R. S. and Bremner, F. J. A method for rapid conditioning of stable avoidance bar pressing behavior. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 393-394.
- Field, G. E. and Boren, J. J. An adjusting avoidance procedure with multiple auditory and visual warn-

- ing stimuli. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 537-543.
- Freedman, P. E. and Callahan, B. S. Discriminative compartmental CSs in shuttlebox avoidance acquisition. *Psychonomic Science*, 1968, 12, 341-342.
- Forgione, A. G. The elimination of interfering response patterns in lever-press avoidance situations. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 51-56.
- Gilbert, R. M. and Croskerry, P. G. Auditory and visual control over chained operants: II. Replication and effects of darkness on auditory control. *Psychonomic Science*, 1969, 17, 47-48.
- Green, R. T. Threshold for electric shock of laboratory rat. *Animal Behaviour*, 1958, 6, 72-76.
- Grossen, N. E. and Bolles, R. C. Effects of a classical conditioned 'fear signal' and 'safety signal' on non-discriminated avoidance behavior. *Psychonomic Science*, 1968, 11, 321-322.
- Hake, D. F. Actual *versus* potential shock in making shock situations function as negative reinforcers. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 385-403.
- Herrnstein, R. J. Method and theory in the study of avoidance. *Psychological Review*, 1969, 76, 49-69.
- Herrnstein, R. J. and Hineline, P. N. Negative reinforcement as shock frequency reduction. *Journal of the Experimental Analysis of Behavior*, 1966, 9, 421-430.
- Hineline, P. N. *One shock now or five shocks later*. Paper presented to the Eastern Psychological Association, Philadelphia, Pa., April, 1969.
- Hineline, P. N. and Herrnstein, R. J. Timing in free-operant and discrete-trial avoidance. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 113-126.
- Hoffman, H. S. The analysis of discriminated avoidance. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 499-530.
- Hoffman, H. S., and Fleshler, M., and Chorney, H. Discriminated bar press avoidance. *Journal of the Experimental Analysis of Behavior*, 1961, 4, 309-316.
- Hurwitz, H. M. B. and Dillow, P. V. Discrimination learning under avoidance schedules. In R. M. Gilbert and N. S. Sutherland (Eds.), *Animal discrimination learning*. London: Academic Press, 1969. Pp. 413-454.
- Keehn, J. D. The effect of a warning signal on unrestricted avoidance behaviour. *British Journal of Psychology*, 1959, 50, 125-135.
- Keehn, J. D. Avoidance response latencies as a function of intertrial and signal shock intervals. *Psychological Reports*, 1967, 21, 905-910.
- Keehn, J. D. Consciousness, discrimination, and the stimulus control of behavior. In R. M. Gilbert and N. S. Sutherland (Eds.), *Animal discrimination learning*. London: Academic Press, 1969. Pp. 273-298.
- Keehn, J. D. and Webster, C. D. Rapid discriminated bar-press avoidance through avoidance shaping. *Psychonomic Science*, 1968, 10, 21-22.
- Kelleher, R. T. and Morse, W. H. Schedules using noxious stimuli. III. Responding maintained with response-produced electric shocks. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 819-838.
- Lockard, J. S. Shaping avoidance behavior in restrained monkeys. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 649-652.
- Miller, N. E. Learning of visceral and glandular responses. *Science*, 1969, 163, 434-445.
- Morgan, M. J. Negative reinforcement. In L. Weiskrantz (Ed.), *Analysis of behavioral change*. New York: Harper & Row, 1968. Pp. 19-49.
- Munn, N. L. *Handbook of psychological research on the rat*. Boston: Houghton Mifflin, 1950.
- Rescorla, R. A. Establishment of a positive reinforcer through contrast with shock. *Journal of Comparative and Physiological Psychology*, 1969, 67, 260-263.
- Rescorla, R. A. and Solomon, R. L. Two-process learning theory: relationships between Pavlovian conditioning and instrumental learning. *Psychological Review*, 1967, 74, 151-182.
- Schoenfeld, W. N. An experimental approach to anxiety, escape and avoidance behavior. In P. H. Hoch and J. Zubin (Eds.), *Anxiety*. New York: Grune & Stratton, 1950. Pp. 70-99.
- Sidman, M. Avoidance conditioning with brief shock and no exteroceptive warning signal. *Science*, 1953, 118, 157-158.
- Sidman, M. Some properties of the warning stimulus in avoidance behavior. *Journal of Comparative and Physiological Psychology*, 1955, 48, 444-450.
- Stretch, R. and Skinner, N. Methylphenidate and the stimulus control of avoidance behavior. *Journal of the Experimental Analysis of Behavior*, 1967, 10, 485-493.
- Ulrich, R. Interaction between reflexive fighting and cooperation escape. *Journal of the Experimental Analysis of Behavior*, 1967, 10, 311-317.
- Ulrich, R. E., Holz, W. C., and Azrin, N. H. Stimulus control of avoidance behavior. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 129-133.
- Walsh, M. G. and Keehn, J. D. Avoidance behavior in a bar-pressing situation as a function of release-shock intervals. *Psychological Reports*, 1969, 24, 511-518.
- Zielinski, K. and Soltysik, S. The effect of pretraining on the acquisition and extinction of avoidance reflex. *Acta Biologica Experimentalis*, 1964, 24, 73-87.

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