DISCRIMINATED BAR-PRESS AVOIDANCE[1]

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In this research, we investigated a form of the avoidance paradigm in which impending shock is signalled by a warning stimulus and the avoidance response is a bar press that terminates this warning signal and prevents the occurrence of the associated shock.

One purpose of the research was to document the course of avoidance over an extended number of sessions. The second purpose derives from the observation that some animals do poorly on the avoidance task. Personal communication with other investigators (O. Ray, L. Stein, & G. Heise) and our own laboratory experiences indicated large differences in the performance levels of individual animals. In the present work, we attempted to examine the conditions responsible for these differences.

The research involved four related experiments. In the initial experiment, several rats were subjected to an extensive program of avoidance conditioning. During this period, a criterion for well-developed avoidance was in effect, and, as animals met criterion, their training was discontinued. On the other hand, the animals which failed to reach criterion were retained and run for a sufficient number of sessions until it was clear that continued training was not likely to overcome the deficiency in their performances. They were then subjected to a sequence of experiments in an effort to isolate the variables responsible for their relatively depressed performances.

The technique of performing experiments upon animals which have previously met a given behavorial criterion has a well-established history in experimental psychology and needs no discussion at this time. The present approach, which focuses upon the animals which fail to reach criterion, differs only in detail. Its historical antecedent is in the work of the pathologist; as in pathology, the technique provides an opportunity to examine processes which are often refractory to investigation by more usual methods.

METHOD

Subjects

The *S*s were 10 female rats of Sprague-Dawley stock. They were approximately 90 days old at the start of the experiment and were maintained on a free-feeding diet.

Apparatus

The experimental chamber consisted of a sound-insulated Skinner box, equipped with a one-way-vision window. The walls, manipulandum, and grid floor were wired for electrical shock. The manipulandum was a bar of 0.25- by 0.75-inch aluminum, which projected 1.5 inches into the test chamber and was mounted 1.5 inches above the grid floor. A pressure of 20 grams was required to actuate the microswitch associated with the bar.

Acoustic signals were delivered through a 5-inch speaker mounted against the back wall of the chamber. In all experiments, the warning signal was a pure tone at 3500 cycles per second, with an intensity of 80 decibels (reference, 0.0002 dyne per centimeter squared) when measured in front of the speaker. Tones were programmed through a Magnecord PT 6 A tape recorder. Tape recording of the signals made it possible (through appropriate splicing techniques) to arrange the tones so that their onsets were free of transients.

A series of timers, steppers, and relays was used to establish the several stimulus-response contingencies which the research demanded. The action of this system was coordinated with the acoustic signals by means of a sensitive relay actuated by the electrical output of the tape recorder. All stimuli, shocks, and responses were recorded on an Esterline-Angus operations recorder. Shock was generated on a Foringer shock supply. This device incorporates a 250,000-ohm resistance in series with the animal.

During shock, the polarity of the bars, walls, and manipulandum were continuously scrambled so as to reduce the probability of unauthorized escape.

The circuitry was such that the response was defined as the initial closure of the bar-actuated microswitch. Arranged in this way, bar holding had no effect on the program. In addition, responses in silence, although recorded, had no effect on the programmed sequence of tones and shocks.

Experiment I: The Development of Avoidance

Procedure. Avoidance training proceeded in a sequence of steps:

1. Shock calibration and preliminary escape training.

The animals were introduced into the test chamber; after a period of adaptation, they were run in a single short session during which shock level was adjusted and they were taught to escape. The response was developed through a process of reinforcing (with shock termination) only those behaviors which represented successive approximations to the desired bar press. For all animals, the shaping process required less than 15 shocks and was completed within 20 minutes. During this session, the shocks were presented without tone and were programmed by hand. The shock intensity varied somewhat from animal to animal and was set at a level which yielded persistent and

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vigorous movements. The average shock level was 100 volts ±15 volts when measured across the bars of the grid.

2. Early avoidance.

Avoidance training was initiated with a condition under which tones appeared on a variable-interval schedule, with a mean of 2 minutes and a range of 1 minute. Shock began 4 seconds after the onset of tone, and both the tone and the shock remained on until a bar press occurred. During this and all subsequent phases of the research, a response during the warning period terminated the tone and allowed the animal to avoid the associated shock. Thus, every tone presentation ended in either an avoidance or escape response. This phase of the program consisted of 10 sessions. The animals were run on one session per day; and on each session, 35 tone-shock combinations were programmed.

3. Late avoidance.

After 10 sessions with 2-minute intertone times, the average time between tones was shortened and the number of tones per session was increased in order to increase the amount of data per session. Thus, beginning with Session 11 and continuing thereafter, tone-shock combinations appeared on an average of once every 35 seconds ± 15 seconds, and each session was programmed for 70 tone-shock combinations.

To discriminate among animals, a criterion for well-developed avoidance was defined as asymptotic performance in which the *S* avoided at least 90% of the shocks programmed on each of at least three consecutive sessions.

Results and Discussion. One of the animals developed respiratory infection early in the training process and was discarded. Five of the animals reached criterion performance in an average of 24 sessions. Four of the animals failed to achieve the 90% criterion even though each had received more than 1700 tone-shock pairings.

Figure 1 shows the mean percentage of avoidance responses per session during the first 18 sessions for the five animals which reached criterion.[2] This figure also shows the mean percentage of avoidance responses per session during the first 30 sessions for the four animals which failed to reach criterion. The inset in Fig. 1 shows the data from one animal in each group and serves to illustrate the degree to which the performance of the individual can be represented by curves based upon means.

As Fig. 1 shows, the acquisition of avoidance was slow, and there was considerable variability from session to session. The learning curve tends to exhibit negative acceleration; and according to the figure, the

[2]After the 18th session, the number of animals in the group labeled "criterion animals" was reduced (as the animals met criterion). For this reason, the curve for these animals does not show the portion of the performance in which criterion was met.

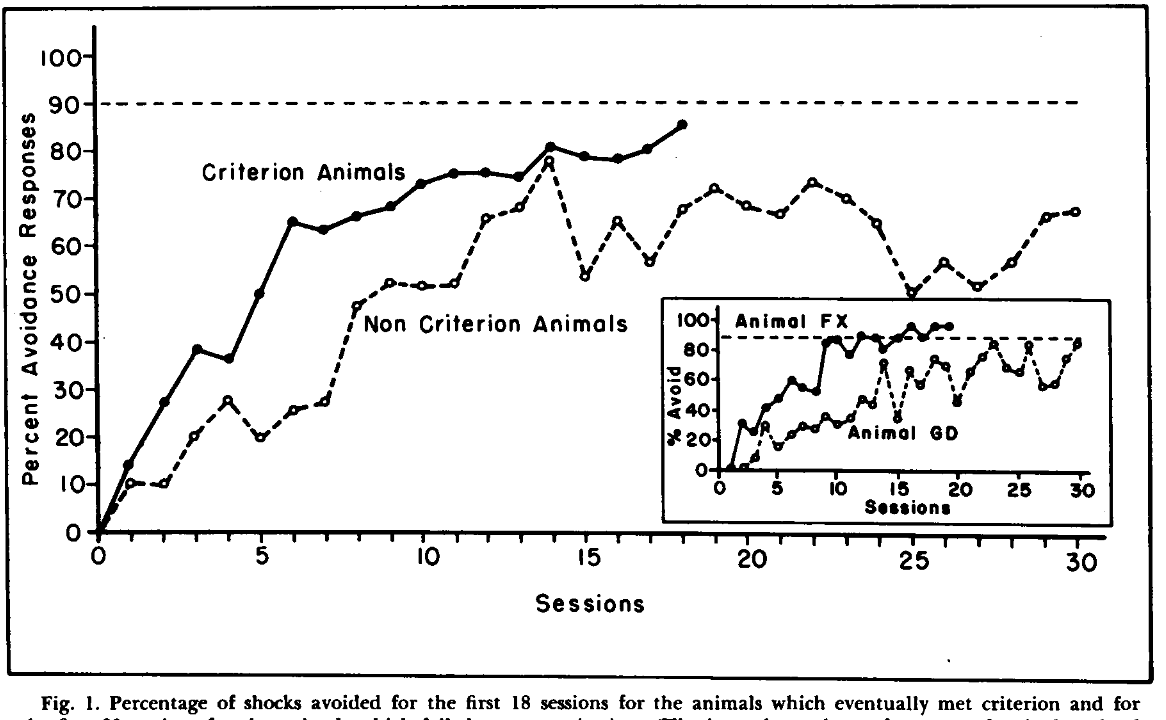

Fig. 1. Percentage of shocks avoided for the first 18 sessions for the animals which eventually met criterion and for the first 30 sessions for the animals which failed to meet criterion. (The inset shows the performance of a single animal from each group.)

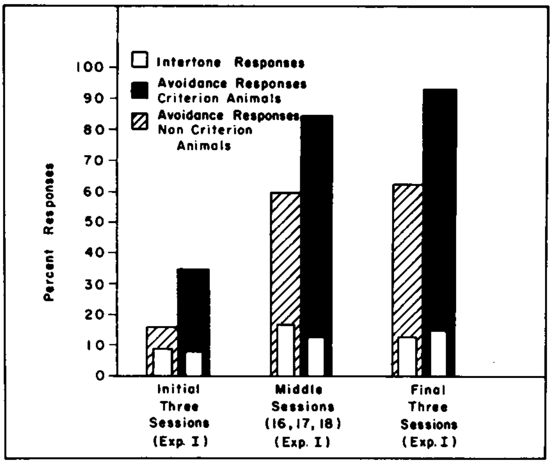

Fig. 2. Intertone responses during the initial, middle, and final sessions of Experiment I.

major difference between the criterion and noncriterion animals appears to be the level of asymptotic performance.

The transition from early to late avoidance occurred on Session 11. As Fig. 1 shows, this change in conditions (an increase in the number of tones per session and a decrease in the intertone time) essentially was free of systematic change in the over-all performance.

One feature of the avoidance phenomenon not revealed in Fig. 1 is that bar presses tended to occur in the intervals between tones. By comparing the probability of a bar press during the 4-second warning period to the probability of a bar press in a silent interval of comparable length, one may obtain an estimate of the degree to which the tone exercises discriminative control over the response. To quantify the intertone responses, we examined the 4-second silent interval that ended 10 seconds before the onset of each tone. Since the interval between tones was variable, the temporal position of this interval was essentially random with respect to the preceding tone.

Figure 2 shows the percentage of these intervals that contain at least one bar press during the initial, the middle, and the final sessions of Experiment I. This figure also shows the percentage of tones that yielded a bar press during these same sessions.

Figure 2 shows that the tendency to bar press during tone exceeded the tendency to press in a comparable interval of silence. Furthermore, although the criterion and noncriterion animals differed in their tendencies to respond during tone, they did not differ reliably in their tendencies to respond in silence.

An analysis of response latencies on the data from the final three sessions of Experiment I was conducted. For the criterion animals, the mean latency of escape from shock was 0.74 second, whereas the mean latency of avoidance was 2.53 seconds. This is a difference which is statistically significant, with $P < .01$. For the animals which failed to achieve criterion, the comparable latencies were 0.75 and 2.50 seconds, respectively. Again, the difference between the latency of escape and the latency of avoidance is statistically significant ($P < .01$). Because the difference between the criterion and noncriterion animals is not reliable either in their escape or avoidance latencies, it seems clear that the differences in performance can not be accounted for in terms of different response speeds.

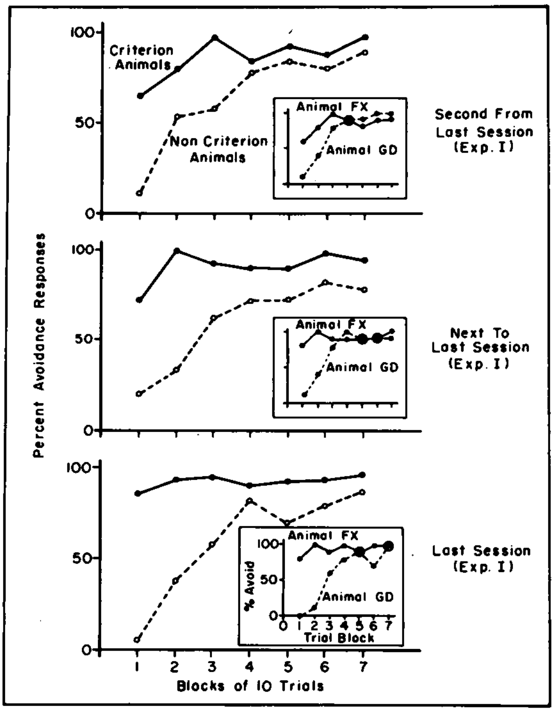

Fig. 3. Within-session performance during the final three sessions of Experiment I. (The inset shows the performance of a single animal from each group.)

Although the animals from both groups were observed during many of their sessions, we were also unable to detect any major differences between the criterion and noncriterion animals in response topography. With tone onset, the animals typically would stop dead in their tracks, a behavior often described as freezing. After an initial period of freezing (about 1:5 seconds), the animals would slowly execute the bar press. However, if an animal had failed to respond during the warning signal and shock had come on, the bar press would be executed rapidly and with considerable vigor.

Figure 3 illustrates the within-session performance for Animals FX and GD. This figure shows the mean percentage of avoidance responses per block of 10 trials for each of the final three sessions in Experiment I (the criterion session for the animals which achieved 90% avoidance and Sessions 28, 29, 30 for the rest). The insets show the within-session performance for the two animals whose learning curves were seen in Fig. 1.

As Fig. 3 shows, probability of avoidance decreased between sessions and increased within sessions. This phenomenon, tentatively identified as warm up, appeared in the records of all animals; but, by the end of Experiment I, the effect was greatly attenuated in the performance of the animals which reached criterion. The observation that when avoidance was well developed, sessions occasionally occurred in which no shocks at all were received revealed that warm up is not a necessary condition for avoidance. However, even with the most proficient animals, some warm up occurred in most sessions. Examination of Fig. 3 reveals, further, that the magnitude of the warm up was the critical factor in determining whether or not a given animal reached the criterion of 90% avoidance on each of three consecutive sessions. Figure 3 also shows that the noncriterion animals performed at a high level during the last half of the session; and the record of Animal GD indicates clearly that the performance of the noncriterion animals during the latter part of the session can on occasion equal, and even surpass, that of the criterion animals.

Experiment II: The Role of Shock Intensity in Warm Up

It seemed possible that the noncriterion animals might be relatively insensitive to the shock levels used in Experiment I. If so, an increment in shock intensity for these animals might produce a more rapid shift from escape to avoidance and hence yield a performance similar to that in the records of the criterion animals. In Experiment II we attempted to evaluate this possibility.

Method. Two of the four noncriterion animals were randomly chosen; and beginning on the 31st session, the shock intensity was increased by 200 volts over the levels previously used (92 and 103 volts). (In all other respects, the conditions were the same as those described in Experiment I.) The other two animals were maintained at their previous shock levels (87 and 114 volts) for 10 additional sessions as a control for extended exposure to the avoidance schedule. In the 11th session (Session 41 counting from the beginning of Experiment I), the shock intensity was increased by 200 volts for the control animals, and both groups continued under high shock (300 ± 14 volts) for 10 sessions. Thus, the experiment involved 20 sessions beyond the 30 reported in Experiment I. For two of the animals, all 20 sessions were run under high shock. For the other two animals (the controls), only the last 10 sessions were run under high shock.

Results and Discussion. The increase in shock intensity modified the within-session performance, but not in the expected manner. The initial effect of increased shock intensity was a small decrement in the performance during the last 40 trials of the session. The performance during the first 30 trials (the warm-up period) was unchanged. This reduction in avoidance was transient, however; and after 10 sessions of exposure to the high-intensity shock, the performance during the last 40 trials of each session improved to what it had been under low-intensity shock.

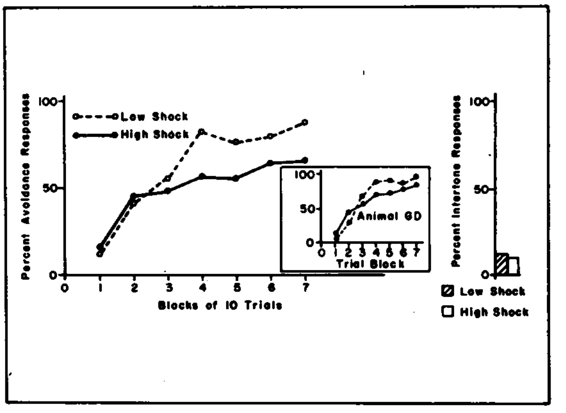

Fig. 4. Experiment II: Within-session performance during the final three sessions under low-intensity shock and during the initial three sessions under high-intensity shock. (The inset shows the performance of Animal GD, whereas the bar graph shows the group's intertone responses during these periods.)

Figure 4 illustrates the initial effect of increasing the intensity of shock. It shows the mean within-session performance of all four animals in the three sessions which preceded the increase in shock and in the three sessions which immediately followed the increase in shock. The bar graph shows the mean levels of intertone responding during these periods, and the inset shows the performance of Animal GD.

As Fig. 4 shows, the performance during the initial 30 trials is unchanged following the increase in shock intensity, but the performance during the last 40 trials is somewhat depressed. In order to evaluate the reliability of this decrement, the percentages during the last 40 trials were transformed according to Bliss' arcsine function described in Snedecor (1946, p. 316). The transformed scores were then subjected to a two-way analysis of variance with time of shock increase (immediate, or after 10 sessions on low shock) as one variable and shock intensity (100 volts vs. 300 volts) as the second variable. This analysis yielded a nonsignificant interaction (time of shock increase vs. shock intensity) and a nonsignificant effect for the first variable (time of shock increase). However, the effect of shock intensity was statistically significant ($P < .05$). From these results, we concluded that extended exposure to low shock did not change the within-session performance, nor did it interact with the effect of shock increase. Apparently, the decrement in performance during the last 40 trials of the sessions immediately following the increase in shock are solely the result of that increase. Because the curves overlap during the first 30 trials, the increase in shock clearly did not systematically affect the early stages of warm up. As Fig. 4 also shows, the increase in shock intensity produced little, if any, change in the level of intertone responding.

Although most drive theories would predict that rate of avoidance is an increasing function of shock intensity, the results of Experiment II have not confirmed this prediction. This finding is in essential agreement with results reported by other workers in the area of aversive control. In an avoidance procedure quite similar to ours, Stone (1960) reported no difference between a 0.5-milliampere and 1.0-milliampere shock. Kimble (1955) found decreases in latency with increased shock intensity; but as Solomon and Brush (1956) suggested, these decreases may only represent differences in the shock level at which various animals will make the initial shift from escape to avoidance. In the present research, we had thought that an increase in shock intensity might facilitate the shift from escape to avoidance in animals which had previously shown a long history of avoidance. Clearly, no such facilitation occurred.

By the end of Experiment II, each of the noncriterion animals had been exposed to 50 sessions of avoidance training, a process involving more than 3000 trials. Still, day after day, these animals would take shock during the early part of the session but avoid it during the latter part. The results of Experiment II indicated that this unusual performance did not result from a relative insensitivity to shock. In Experiment III, we attempted to examine a second variable which we thought might be responsible for the warm up.

Experiment III: The Role of Tone-shock Pairings in Warm Up

During the early phases of each session, shocks occurred at the end of most tones. Therefore, with the noncriterion animals, the emergence of avoidance on each session might depend critically upon the pairing of shock with tone. Experiment III was designed to evaluate this possibility.

Method. Experiment III, in which the four noncriterion animals were used, involved 6 sessions beyond the 50 reported previously. The conditions for these sessions were identical to those in the latter portion of Experiment II, except that 80 rather than 70 trials were programmed and on alternate sessions (52, 54, and 56) the tone was disconnected during the first 40 trials. After 40 unsignalled shocks had been delivered and without interrupting the session, the tone was reconnected and the remaining 40 trials were run.

The procedure of introducing the treatment (unsignalled shock) on alternate sessions permitted intersubject replication and also made it possible to determine whether or not the effects of the treatment were reversible.

In order to prevent the fortuitous punishment of bar presses (*i.e.*, to keep the time between bar presses and shock at least 4 seconds), the circuit was such that during the unsignalled shock period the animals could avoid shocks provided that a response occurred during the 4-second period preceding the onset of each shock. Since shocks were programmed irregularly and were unsignalled, however, the probability of nondiscriminated avoidance was expected to be low.[3] Once shock was delivered, it remained on until terminated by a response.

Results and Discussion. Figure 5 shows the results of Experiment III. The top set of coordinates shows the percentage of shocks avoided per block of 10 trials during Session 51, when all 80 programmed shocks were preceded by tone, and during Session 52, when only the last 40 shocks were preceded by tone. As in previous figures, the inset shows the performance of Animal GD. Figure 5 shows that Session 51 yielded a typical warm up, whereas very little warm up occurred on Session 52, when 40 unsignalled shocks preceded the introduction of tone.

The middle set of coordinates in Fig. 5 shows the performance on Sessions 53 and 54. When tone preceded each programmed shock (Session 53), a large warm up was seen. On Session 54, however, shock was again unsignalled during the first 40 trials, and, as

[3]This expectation was confirmed by the fact that less than 1% of the shocks were avoided during the period of unsignalled shock.

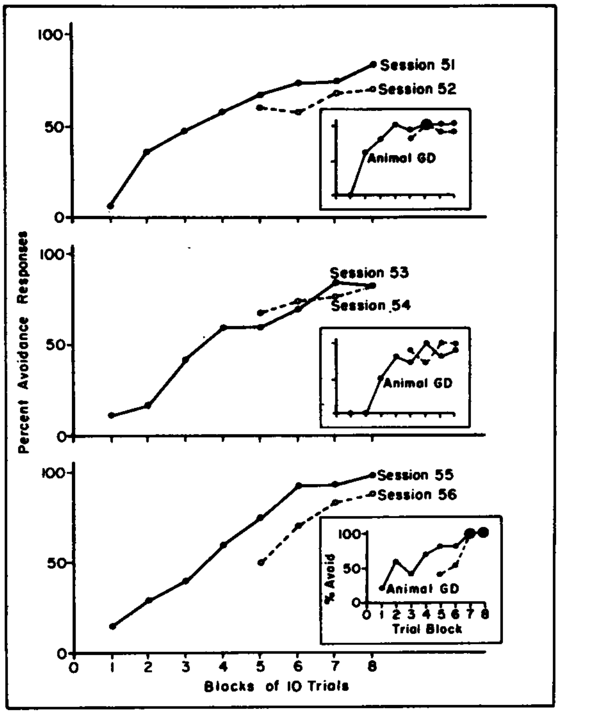

Fig. 5. Experiment III: Within-session performance on control and on treatment sessions for all noncriterion animals and for Animal GD only. [During treatment sessions (52, 54 and 56), the tone was disconnected during the first 40 trials.]

was found previously, the animals exhibited very little warm up when tone was finally introduced. The bottom set of coordinates in Fig. 5 shows the data from Sessions 55 and 56. The results from these sessions again confirm the finding that a sequence of unsignalled shocks can greatly reduce warm up and that the effect is largely limited to the session on which the shocks are applied.

As was suggested in the introduction to Experiment III, shocks occur at the end of most tones, during the initial phases of warm up. Before Experiment III, it had seemed possible that these tone-shock pairings were necessary to re-establish some form of association between tone and shock. However, since Experiment II revealed that warm up can be greatly reduced without pairing tone and shock, relearning of a tone-shock association is probably not a necessary component of warm up.

When shock was delivered during Experiments I, II, and III, it remained on until terminated by a bar press. Since this was true for unsignalled as well as signalled shocks, the possibility existed that some process indigenous to the response itself was the critical factor in warm up.

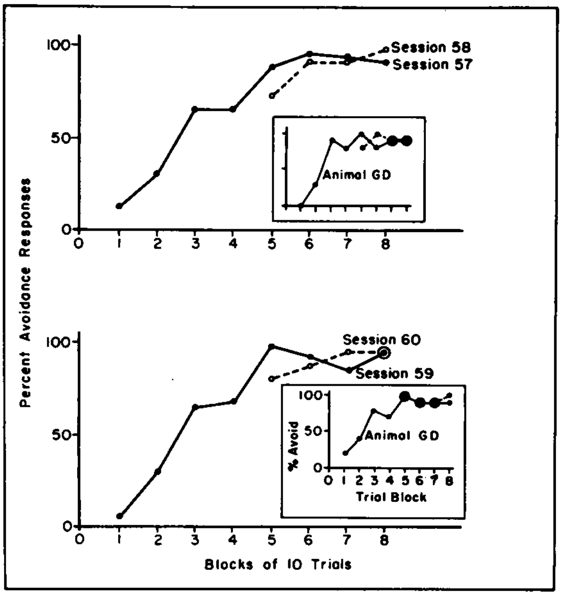

Fig. 6. Experiment IV: Within-session performance on control and on treatment sessions for all noncriterion animals and for Animal GD only. [During treatment sessions (58 and 60), the tone was disconnected and the bar was inaccessible during the first 40 trials.]

Experiment IV: The Role of the Response in Warm Up

In order to evaluate the contribution of the response to the warm-up phenomenon, Experiment III was repeated but modified so that the bar was inaccessible during unsignalled shock.

Method. To gain control over the accessibility of the bar, a remotely movable, transparent shield was installed in the experimental chamber. It consisted of a U-shaped channel constructed of three pieces of 0.25-inch lucite, each measuring approximately 2 by 8 inches. One end of the channel was firmly fastened to a rod which passed through the chamber and could be rotated from outside the box. The rod was parallel to the front wall and ran high above the bar, about 0.5 inch from the ceiling. The arrangement was such that by rotating the rod it was possible to swing the shield into either of two positions: up or down. In the down position, the shield covered the bar and ran from floor to ceiling with its entire length fixed against the front wall. In the up position, the shield was flat against the ceiling and the bar was accessible.

Experiment IV followed the general procedure of Experiment III. The four noncriterion animals were used, and it involved 4 sessions beyond the 56 reported previously. It differed from Experiment III in certain details:

1. During the 40 trials of unsignalled shock, the shield was down so that the bar was inaccessible.
2. Since escape was impossible during unsignalled shock, the unsignalled shocks were programmed to automatically terminate after 0.75 second (the mean escape latency found in Experiment I).
3. After 40 unsignalled and inescapable shocks had been delivered, the shield was lifted to the up position and the tone was reconnected without interrupting the session. (At this point the animals then had the first opportunity to either avoid or escape shock.)
4. For control sessions, the shield was moved to a position along the rod such that the bar was accessible even when the shield was down.
5. During control sessions, the shield was in the down position for the first 40 trials; then, the shield was lifted to the up position and the remaining 40 trials were run without interrupting the session.

Thus, during Sessions 58 and 60 of Experiment IV, the animals received 40 unsignalled shocks with the bar visible but inaccessible. Then, the shield was lifted and 40 "standard" trials were run. On control days (Sessions 57 and 59), all 80 trials were "standard" in the sense that the bar was available and the shocks were always preceded by a warning signal. The inclusion of the shield during control sessions made it possible to compensate for whatever effects were produced by the shield itself and by the shield having been moved.

Results and Discussion. Figure 6 shows the percentage of avoidance responses per block of 10 trials during the four sessions of Experiment IV. Its format is similar to that of Fig. 5.

According to Fig. 6, 40 unsignalled and inescapable shocks almost completely eliminated warm up, and the effects of these shocks were restricted to the sessions during which they were applied. On Sessions 57 and 59, a normal warm up occurred. On days when unsignalled and inescapable shocks were delivered before the introduction of tone, very little warm up occurred.

One factor which prevents an unambiguous interpretation of the results of Experiment IV is the possibility that during unsignalled and inescapable shock, the animals were making phantom bar presses. Hearst, *et al.* (1960) has described such behavior, and in the present experiment, this behavior would manifest itself as bar-press-like movements which occur despite the presence of the shield. However, observations of the animals during the unsignalled shock period tended to discount this possibility. During the first shock or two, the animals typically moved to the vicinity of the bar. With continued shock trials, however, this behavior rapidly gave way to a pattern in which the animals spent most of their time crouching and the response to shock was a vigorous leap from the grid floor. Since the leap was seldom in the direction of the bar, the animals clearly were not making phantom bar presses during shock.

Although these observations coupled with the data in Fig. 6 indicated that the response was not the critical component of warm up, they did not necessarily indicate that shock is the major variable in this process. It seemed possible (though unlikely) that time in the box rather than shock itself was the necessary and sufficient condition for the alleviation of warm up. As a control for this possibility, the animals were run for one additional session, which differed from "standard" sessions only in that the animals were permitted to remain in the box for 25 minutes (the time required for 40 trials) before the program of tone-shock was instigated. Because a typical warm up was observed during this session, it may be concluded that time in the box was not of major importance.

Apparently, the aversive stimulus, shock itself, was a sufficient condition for the elimination of warm up. For this reason, the detailed explanation of warm up will probably be found in processes which are induced by aversive stimulation. Although we cannot specify the detailed characteristics of these processes at present, they probably are motivational in nature and involve the gradual development of emotionality in one form or another, and the warm up itself probably reflects this development. In discussing the role of such motivation in conditioning, Spence (1956, p. 186) suggests that " . . . the drive level operating at the time of the conditioned anticipatory response is a function of the residual effects of the internal response (r_e) to the noxious stimulus of the preceding trials. That is, such emotional responses are assumed to have a relatively persisting effect that extends well beyond the range of temporal intervals usually employed in conditioning experiments . . . " The results of the present research are clearly in accord with this position.

A major question arises, however, when one considers the problem of emotionality in relation to the results of Experiment I. What is responsible for the large individual differences in the magnitude of warm up? Is it differences in some base level of emotionality, differences in the role of such emotionality in avoidance, differences in the rate at which shock-induced emotionality grows during the session, or differences in the rate at which the emotional after-effects of shock dissipate between sessions? Clearly, further research is necessary if these and related questions are to be answered.

A second question resulting from the present work is concerned more directly with methodology. Although warm up is not uncommonly mentioned in the literature, many experimenters treat the process as a transition phenomenon and report only the results from the final portions of the sessions (Sidman, 1953; Verhave, 1959; etc.). However, this practice may tend to obscure certain critical information. If warm up represents the reinstatement of a shock-induced motivational process, one may reasonably expect that this process would play an important role in the performance achieved during the latter part of sessions where warm up has occurred. If a given experimental operation then modifies this performance, it becomes important to determine whether the operation affected the motivational aspect of the behavior, or whether, on the other hand, it affected the associative aspect of the behavior. An analysis of the effects of the operation on warm up itself probably would help to clarify the issue.

SUMMARY

A group of rats was subjected to an avoidance paradigm in which electrical shock was always preceded by a warning tone. The conditions were such that a bar press during tone terminated the warning signal and enabled the animal to avoid the associated shock.

After approximately 24 sessions, more than half of the animals had reached a stage of performance in which at least 90% of the shocks were avoided. Examination of the performance during each session revealed that the behavior of the remaining animals was characterized by a warm up which occurred during the early part of each session. Additional observations and experiments revealed that:

1. Differences in the tendency to exhibit warm up were not reflected in differences in response topography, nor were they reflected in differences either in the latency of the escape or the avoidance response.
2. Warm up was not due to a relative insensitivity to the levels of shock used.
3. Warm up did not involve a relearning of the association between tone and shock.
4. Warm up did not involve a process which required the making of the operant response.

5. Warm up apparently reflects the development of a motivational process resulting from the occurrence of shock itself.

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