

**RAPID ACQUISITION OF DISCRETE-TRIAL  
LEVER-PRESS AVOIDANCE: EFFECTS  
OF SIGNAL-SHOCK INTERVAL<sup>1</sup>**

DAVID F. BERGER AND F. ROBERT BRUSH

STATE UNIVERSITY OF NEW YORK COLLEGE AT CORTLAND AND  
SYRACUSE UNIVERSITY

Acquisition of discrete-trial lever-press avoidance learning was studied in three experiments. Experiment I compared a new training procedure, which produces rates of lever-press avoidance learning comparable to those obtained in shuttle boxes, with a "conventional", less efficient training procedure. A factorial design was used to compare continuous *versus* intermittent shock and a long-variable *versus* a short-fixed signal-shock interval. Learning was best in the groups trained with the long and variable interval and poorest in those trained with the short and fixed interval. Type of shock had no effect. Experiment II separated the effects of duration from those of variability of the signal-shock interval. Fixed and variable intervals of 10 and 60 sec were tested and duration was the only significant factor. Experiment III addressed the effect of the differential opportunity to avoid provided by long signal-shock intervals by varying this interval from 10 to 60 sec in 10-sec steps. Only the 10-sec group showed slow acquisition relative to the others. Analysis of avoidance response latencies showed that the distributions for all groups were positively skewed and that skewness increased with increasing duration of the signal-shock interval. At intervals longer than 20 sec, the animals made progressively less use of their increased opportunity to respond. The data do not support the opportunity-to-respond interpretation of the effects of duration of signal-shock interval and suggest that some type of inhibitory process may block lever-press avoidance learning at intervals as short as 10 sec. The significance of these findings for species-specific defense reaction and preparedness theories was emphasized.

*Key words:* avoidance, rapid acquisition, discriminated lever press, rats

A number of authors have noted that different forms of the avoidance response differ in efficiency and ease of acquisition (*e.g.*, Bolles, 1971; Hoffman, 1966; Meyer, Cho, and Wesemann, 1960). The lever-press response, in particular, has been reported by several investigators as difficult for rats to learn, with many never acquiring it (*e.g.*, D'Amato and Schiff, 1964; Meyer *et al.*, 1960). By contrast, relatively few rats fail to acquire the shuttle response (Brush, 1966) and typically none fail to

learn a jump-out response (Baum, 1965; Denny, 1971; Mackenzie, 1974).

Some authors (*e.g.*, Hoffman, 1966; Meyer *et al.*, 1960) have suggested that lever-press avoidance learning is retarded because responses like freezing and lever holding compete with the active lever-press response. Support for this notion comes from experiments by Feldman and Bremner (1963), in which avoidance acquisition was facilitated by punishment of freezing responses during the warning signal; similarly, lever holding has been reported to be reduced by electrifying the lever (Myers, 1959), and by punishing lever holding longer than a given duration (Feldman and Bremner, 1963). Alternative suggestions have proposed that the rat is "contra-prepared" (Seligman, 1970) to learn this response in an avoidance training paradigm, or that the lever-press response is not in the repertoire of species-specific defense reactions (SSDRs) of the rat (Bolles, 1970, 1971, 1972). Both of these suggestions are *post hoc* interpretations that depend heavily on negative results and invoke gratuitous assumptions

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about the nature of the organism to account for the learning difficulty. Alternatively, the training conditions could be at fault. The present paper reports a series of experiments using a successful lever-press avoidance training procedure, which is a modified version of that first reported by Berger (1969). It used neither punishment of competing responses, nor prior shaping of the lever response (Giulian and Schmaltz, 1973), nor prior escape training (*e.g.*, D'Amato, Keller, and DiCara, 1964).

Three variables differentiate the Berger (1969) procedure from "conventional" lever-press avoidance training procedures. The first is that intermittent and widely spaced shock pulses were used, rather than the traditional continuous shock. Data from D'Amato *et al.* (1964) and others suggest that this would lead to facilitation. The second difference is that the duration of the signal-shock interval was relatively long and variable compared to a short fixed value of 5 or 10 sec for the "conventional" procedures. Data from Biederman (1969), Bolles, Warren, and Ostrov (1966), Hoffman (1966) and others suggest that this would also lead to facilitation. The third difference is that a relatively long safe period with a distinctive "safety signal" was used, rather than the more usual brief (*e.g.*, 30 or 60 sec) intertrial interval without a safety signal. Data from Bolles and Grossen (1969), Bower, Starr, and Lazarovitz (1965), Brush (1962), and Denny (1971) suggest that a long and/or distinctively cued safe period would also facilitate avoidance acquisition.

Berger (1969) indicated that rapid acquisition of lever-press avoidance behavior might be achieved by using a combination of the variables listed above. The present paper reports experiments that attempted to identify the effects of the first two of these variables, or their combination. Experiment I compared intermittent *versus* continuous shock, and compared the long-variable signal-shock interval of Berger (1969) with the "conventional" short-fixed signal-shock interval. In that experiment, rapid acquisition was found using the long-variable interval, so Experiment II separated the effects of duration and variability of the signal-shock interval. The effectiveness of a long interval raises the question of greater opportunity to respond (see Biederman, 1969; Bolles, Warren, and Ostrov, 1966),

so the duration of the signal-shock interval was examined parametrically in Experiment III.

## EXPERIMENT I

### METHOD

#### *Subjects*

The sixteen experimentally naive female Sprague-Dawley rats from the Carworth Farms, New City, New York were approximately 90 days old at the start of training and were allowed continuous access to food and water except during their daily conditioning sessions.

#### *Apparatus*

Four BRS Foringer series 900 chambers were used for conditioning. They were 36 cm long, 24 cm wide, and 29 cm high. The disc-shaped levers were 18 mm in diameter and required an average of 12 g (0.12 N) to operate. The boxes were each enclosed in a sound-attenuating outer chamber. The warning signal was an 800-Hz tone, which increased the 72-dB background noise level by 7 dB (SPL). The safety signal was a 1-Hz flashing light generated by pulsing 28 V through two 14-V (GE 1893) bulbs in series; the bulbs were centered over the box on the ceiling of the outer chamber. Shock was generated by BRS Foringer SG 901 Constant Current sources and scrambled by BRS Foringer SC 901 shock scramblers. Shock intensity, when measured by placing an ac milliammeter across the grid, averaged 2 mA. Throughout all sessions, general illumination was provided by a house-light, which was a 28-V (GE 1820) cue light located 5 cm over the lever and operated at 20 V from an isolated ac source.

*Experimental design.* A 2 × 2 factorial design was used. The first factor was the kind of shock, either continuous or intermittent. The second factor was the duration and constancy of the signal-shock interval. In one case, it was fixed at 10 sec (F-10), in the other it was variable and averaged 70 sec (V-70). Four subjects were assigned nonsystematically to each of the four conditions.

#### *Procedure*

Each animal was allowed to explore the box during an initial session and on the next day avoidance training began. The daily sessions

were 51 min long and began approximately 2 min after the animal was placed in the box, during which time only the houselight and fan were on. Avoidance training continued for 15 days.

For all experimental groups a trial was initiated by presentation of the 800-Hz tone that served as the warning signal (WS). The WS remained on until it was terminated by a lever-press, which simultaneously turned on the 1-Hz flashing light that served as the safety signal (SS). In all cases the SS remained on for 5 min, at which time the next trial was initiated, *i.e.*, the SS was terminated and the WS again presented. Responses during the 5-min SS were counted but had no effect on its duration. However, the sessions were of fixed duration so that the last trial on any day could be terminated at any time by the end of the 51-min session, at which time only the houselight and fan remained on until the animal was removed. Total WS duration for each session was recorded which, when divided by the number of trials, yielded mean response latency for the session. Approximately 10 trials could occur in each 51-min session, but the actual number of trials in each session depended on the animal's response latencies. If an animal failed to respond, the entire session could be spent in the presence of the first WS and subsequent shocks.

For the F-10, continuous shock group (F-10-C) the interval between WS onset and shock onset was fixed at 10 sec. A lever press during the signal-shock interval (avoidance response) terminated the WS, avoided the shock, and initiated the 5-min SS. Once shock came on, both WS and continuous shock remained on until terminated by a lever press (escape response), which also was followed by the 5-min SS.

For the F-10, intermittent shock group (F-10-I), conditions were identical to the above group except that intermittent 2-mA shock was used. Shock pulses were 0.5 sec in duration, and the first shock pulse was scheduled to occur 10 sec after WS onset. Subsequent shocks were delivered on a VI 1-min schedule by a continuously running programmer. A lever press during a 0.5-sec shock pulse terminated the shock and thus could reduce its duration.

For the V-70, continuous shock group (V-70-C), the interval between WS onset and

shock onset varied between a minimum of 10 sec and a maximum of 130 sec. As in the F-10-C group, a lever press during the WS-shock interval terminated the WS, avoided shock and initiated the 5-min SS; in the absence of an avoidance response, both WS and shock remained on until terminated by the lever-press response. Note that this procedure allows for occasional avoidance latencies as long as 130 sec.

For the V-70, intermittent shock group (V-70-I), conditions were identical to the V-70-C group, except that intermittent 2-mA shock was used. The interval between WS onset and the first shock pulse (0.5-sec duration) varied between 10 and 130 sec. Subsequent shocks, as in the F-10-I condition, were arranged on a VI 1-min schedule. A response before the first shock pulse was defined as an avoidance, whereas a response after the first shock pulse, even if it occurred during the variable intershock interval, was defined as an escape.

On relatively rare occasions, long periods in continuous shock were terminated by the experimenter, and a "free" 5-min safe period was given if an animal appeared to be severely weakened by the shock. During the first session, this occurred either three or four times for each animal in the F-10-C group, and either one or two times for two animals in the F-70-C group. By the second session, only two animals in the F-10-C group required this shock termination by the experimenter two and three times, respectively.

## RESULTS

Since the number of trials varied in each session, the percentage of trials on which avoidance responses occurred was calculated for each animal for each session. The median per cent avoidance responses for blocks of five sessions was then obtained for each animal, and Figure 1 presents the group medians of those medians. It is apparent from the figure that the V-70 groups were superior to the F-10 groups; the performance of the V-70 groups surpassed 50% by the second block, whereas the F-10 groups never exceeded 10%. Animals trained with intermittent shock performed at essentially the same levels as those trained with continuous shock.

To confirm these effects statistically, a factorial analysis of variance, which included

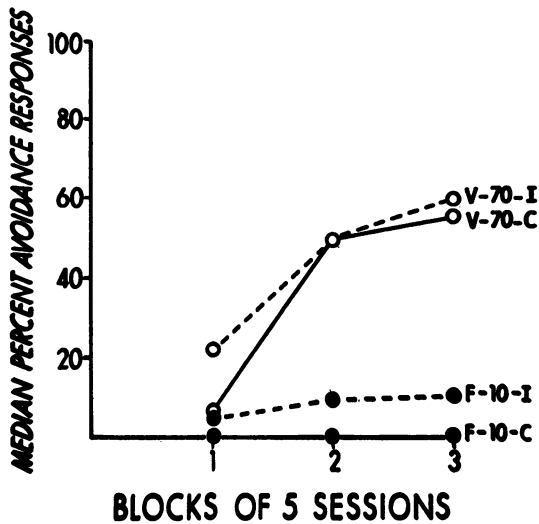


Fig. 1. Median per cent avoidance responses over blocks of five sessions for Experiment I. The open symbols are the variable 70-sec and the solid symbols are the fixed 10-sec conditions. The solid lines represent the continuous, and the dashed lines the intermittent shock. Each point value is median of the block median for each animal within each group.

both independent variables and session blocks was computed. Because of skewness, this analysis was performed on the square root + 1 of the individual block medians. The difference between the V-70 and F-10 groups was significant,  $F(1, 12) = 9.1$ ,  $p < 0.025$ , whereas the effect of type of shock (I versus C) was not significant,  $F < 1$ . The effect of sessions was significant,  $F(2, 24) = 6.7$ ,  $p < 0.005$ , and interacted with the signal-shock interval,  $F(2, 24) = 4.2$ ,  $p < 0.05$ . Follow-up analyses showed that only the V-70-C and F-10-C had different rates of acquisition. No other group's rate of acquisition were significantly different.

In the continuous shock groups, responding during the 5-min SS period was virtually zero. In contrast, responding during the SS period in the V-70-I group was frequent early in training and diminished as training progressed; good discriminative control was apparent several sessions after avoidance responding had reached asymptote. In the F-10-I group, responding during the SS was variable: some animals had a low level of responding whereas others responded frequently; in both cases, the responding in SS did not change appreciably over sessions. Thus, responding during the SS period was unrelated to avoidance acquisition, except in the V-70-I group.

Mean response latency was calculated for each animal for each session. This measure, which combines both avoidance and escape latencies, decreased significantly as training progressed, and intermittent shock resulted in significantly longer latencies than did continuous shock. These results probably reflect the combined effects of longer escape latencies in the intermittent shock groups and different rates of acquisition of both escape and avoidance responding in the various groups.

#### DISCUSSION

The results clearly demonstrate that rats can learn a discrete-trial lever-press avoidance response in approximately 50 trials without prior escape training or response shaping. These results contrast markedly with those of D'Amato and his coworkers, whose best group (see low intensity discontinuous shock group in D'Amato and Fazzaro, 1966) reached a level of avoidance responding comparable to our V-70 groups, but required 250 avoidance training trials after 40 response-shaping trials. Note that, as in D'Amato's experiments, no animals were dropped from this experiment for failure to learn.

Another surprising finding of the present experiment is the absence of a facilitatory effect of intermittent shock, which again differs greatly from the results of D'Amato and Fazzaro (1966) and D'Amato, Etkin, and Fazzaro (1968) who also used the lever-press response and shock intensities in the same range as ours. However, their shock pulses occurred more frequently (0.2 sec on, 2.0 sec off) than those in the present study (0.5 sec on, VI 1-min off). Furthermore, their signal-shock and intertrial intervals were shorter than ours, and they typically ran 300 to 400 trials per session, compared to approximately 10 trials per day in our experiment. Interactions between type of shock and any or all of these variables could account for the discrepancy between their results and ours. Our intermittent shock animals often responded after the first pulse terminated so that, as D'Amato *et al.* (1964) suggested, the stimulus conditions during an escape response were similar to those during an avoidance response. However, no beneficial effect from this possible generalization from escape to avoidance responding was observed in this experiment. Furthermore, the animals in the F-10-I group failed to learn to avoid.

Another somewhat contradictory finding of this experiment was that 2-mA shock intensity supports avoidance learning. Several investigators have reported an inverse relation between shock intensity and avoidance learning (e.g., D'Amato and Fazzaro, 1966, with lever-press, and Moyer and Korn, 1964, with shuttle responses) with poor performance at intensities in the 2-mA range.

Clearly, the major variable in this experiment that facilitated avoidance learning was the use of the V-70 procedure. Since in comparison with the F-10 procedure, duration and constancy of the signal-shock interval were confounded, we cannot determine whether it was the longer duration of the interval or its variability that facilitated acquisition. Experiment II addressed this question.

## EXPERIMENT II

This experiment examined separately the effects of duration and constancy of the signal-shock interval that were confounded in Experiment I. Since there were no effects of intermittent *versus* continuous shock in the previous study, we chose to use intermittent shock in this experiment.

### METHOD

#### *Subjects*

Twenty-four experimentally naive female rats of the same strain and age as those employed in Experiment I were obtained from the same source and housed as in Experiment I.

#### *Apparatus*

The apparatus was the same as that used in Experiment I.

*Experimental design.* A  $2 \times 2$  design was used in which the first factor was duration of the signal-shock interval (10 *versus* 60 sec) and the second factor was the fixed *versus* variable duration of the signal-shock interval (mean values of 10 *versus* 60 sec for the variable groups). Six animals were assigned nonsystematically to each of the four conditions. To extend the generality of the results, half the animals of each group were trained, as in Experiment I, with WS = tone and SS = flashing light, whereas the other half were trained with the opposite stimulus conditions, thus counterbalancing for specific stimulus effects.

#### *Procedure*

The procedures used for the intermittent shock groups of Experiment I were modified slightly to fit the present requirements. In the group trained with a fixed 10-sec signal-shock interval (F-10), the procedure was identical to that of group F-10-I of Experiment I. The procedure for the group trained with a fixed 60-sec signal-shock interval (F-60) was identical for the F-10 group, except for the 60-sec duration of the signal-shock interval. Thus, for the F-10 and F-60 groups, the first 0.5-sec shock pulse was delivered 10 and 60 sec, respectively, following WS onset. In both groups, subsequent shocks were delivered on a VI 60-sec schedule.

In the group trained with a variable 60-sec signal-shock interval (V-60), the procedure was identical to that of the V-70-I group of Experiment I, except that the WS-shock interval varied between 0 and 120 sec (mean = 60 sec), rather than between 10 and 130 sec (mean = 70 sec). In the case of the group trained with a variable 10-sec signal-shock interval (V-10), this interval ranged between 0 and 20 sec (mean = 10 sec). For both groups, once the first 0.5-sec shock pulse was delivered, subsequent shocks were arranged by the VI 60-sec schedule. As in Experiment I, 15 daily training sessions followed an initial adaptation session.

### RESULTS

There was no significant difference in number of avoidance responses between the groups trained with different WS and SS combinations, so data from these counterbalanced stimulus conditions were combined in subsequent analyses.

As in Experiment I, the median per cent avoidance responses for blocks of five sessions were obtained and Figure 2 presents group medians of those medians. It is apparent from the figure that the 60-sec groups were superior in avoidance performance to the 10-sec groups. In the 60-sec case, the fixed-interval group tended to perform better than the variable-interval group, whereas the converse was true for the 10-sec groups. It should be noted that the performance of the 60-sec groups achieved 60 to 70% avoidances by the second block, thus replicating the results of the V-70 groups of Experiment I. Similarly, the F-10 group performed at about the same low level of proficiency (20% avoidances) as did the F-10-I

group of Experiment I (10% avoidances). The V-10 group performed at an intermediate level that ranged between 30 and 40% avoidances in the last two blocks of sessions.

These data were analyzed by a factorial analysis of variance using the square root + 1 of the block median per cent avoidance responses. The effect of duration of the signal-shock interval was significant,  $F(1, 20) = 5.9$ ,  $p < 0.05$ , as was the effect of sessions,  $F(2, 40) = 16.3$ ,  $p < 0.001$ . No other effects were significant.

Responding during SS appeared to differ among the groups, and since exposures to SS were contingent on the animal's behavior, comparisons among groups required conversion of these data to response rate during SS. As in the case of the avoidance data, individual median response rates in SS over blocks of five sessions were calculated. Rate of responding during SS was low throughout training for all groups except the F-60 group, which showed an elevated rate during the initial block and progressively lower rates in succeeding blocks.

#### DISCUSSION

The results show that duration, rather than constancy, of the signal-shock interval was the determining factor in the successful discrete-trial lever-press avoidance learning seen in the V-70 groups of Experiment I. The performances of the V-70 groups of Experiment I and the F-60 and V-60 groups of Experiment II were comparable. Similarly, the poor performance of the F-10 groups of Experiment I was again seen in the F-10 group of Experiment II.

As Bitterman (1965) suggested, long signal-shock intervals may result in improved performance simply because the animal has a greater opportunity to make an avoidance response. One way this might happen is that if a high base rate of "nondiscriminated" lever pressing develops during training, this would increase the probability of "adventitious" avoidances, especially during long signal-shock intervals. However, such a high response rate should not be limited to the signal-shock interval, but should be present during the SS as well. Our data do not support this high base-rate interpretation because low response rates during SS were seen in the successful V-70-C (Experiment I) and V-60 (Experiment II) groups. Even in the other two successful groups

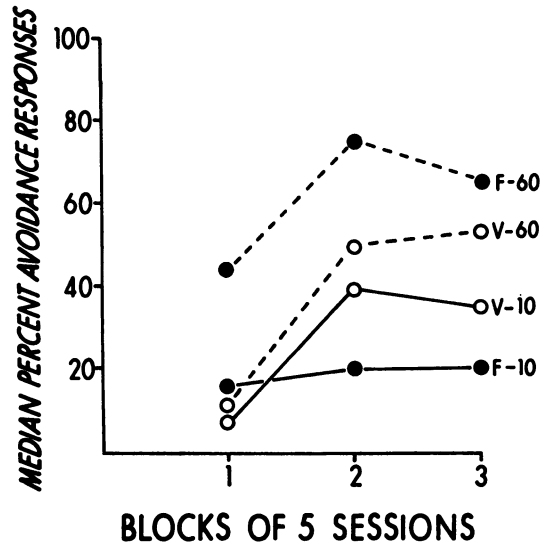


Fig. 2. Median per cent avoidance responses over blocks of five sessions for Experiment II. The open symbols are the variable and the solid symbols the fixed signal-shock intervals. The solid lines represent 10- and the dashed lines 60-sec durations of the interval (averages for variable-interval groups). Each point is the median of the block median for each animal within each group.

(V-70-I of Experiment I and F-60 of Experiment II), where some appreciable SS responding did occur, avoidance responding in some animals preceded the development of SS responding, and in all cases avoidance performance remained at high levels when responding in SS declined with further training.

Even if lever pressing is discriminated, and hence more probable in the presence of WS than SS, an avoidance response would still be more probable with long than with short signal-shock intervals simply because longer latency responses would qualify as avoidances. Indeed, the mean response latencies were greater in the long than in the short-interval groups of Experiment II. It is interesting to note, however, that the terminal latencies of the V-70 groups of Experiment I were approximately 35 sec, well below what was required for successful avoidance. Thus, the animals of these groups were not utilizing the entire interval, at least after asymptotic levels of avoidance probability were achieved. An explanation of the beneficial effect of the long signal-shock intervals that is limited to simple opportunity to respond is thus incomplete at best.

Even though avoidance responding at asymptote did not utilize long signal-shock intervals, it is still possible that long intervals facilitate acquisition by providing a greater opportunity for the animal to contact the avoidance contingency early in training. Thus, early avoidance responses might well be chance occurrences and be distributed throughout the signal-shock interval. Consistent with this view is the fact that in both experiments, response latencies were long early in training and decreased as training progressed. However, since this measure combined both avoidance and escape response latencies it is not possible, in these experiments, to describe the early avoidance latency distribution. Experiment III provides data on this point.

Another feature of these data, which also suggests that response opportunity may function as a learning variable early in training, is the superior performance of the V-10 group relative to that of the F-10 group. The occurrence of intervals as long as 20 sec in the V-10 group may have permitted earlier and more frequent reinforcement of avoidance responses than was possible in the F-10 group. Note that a parallel effect in the V-60 group did not occur, perhaps because the 60-sec groups, whether fixed or variable, have adequate opportunity to respond and be reinforced. However, the variability of the signal-shock interval tended to suppress the performance of the V-60 group below that of the F-60 group, perhaps because of occasional adventitious punishment of approach responses when very short signal-shock intervals happened to occur. Surprisingly, even though adventitious punishment must have occurred with greater frequency in the V-10 than in the V-60 group, this apparently was not sufficient to override the beneficial effect of the occasional long signal-shock intervals in the V-10 schedule.

Finally, the counterbalancing of the tone and flashing light as WS and SS gave some information on the role these signals played in controlling the rats' behavior in these experiments. Although those animals that had WS = tone and SS = flashing light learned to avoid somewhat faster than those trained with these cues reversed, this apparent difference was not statistically reliable. This result agrees with that of D'Amato *et al.* (1964), who also found no difference in the avoidance perform-

ance of their discontinuous shock groups trained with a light *versus* a noise CS. Therefore, these findings suggest that our animals were not just lever pressing to escape from the tone or to get the flashing light, but that their behavior was under the control of the escape/avoidance contingencies and the appropriate signals.

### EXPERIMENT III

Since the previous experiments showed that duration of the signal-shock interval was the major variable that resulted in successful avoidance acquisition, this experiment examined this variable parametrically. Furthermore, to assess the role of response opportunity, a more detailed analysis of avoidance response latencies at a variety of signal-shock intervals was needed. If variation in avoidance performance is determined by simple opportunity to respond, *i.e.*, by the theoretical probability of a response occurring at any time, *t*, during the signal-shock interval, one would expect avoidance performance to be a linear increasing function of duration of the interval.

### METHOD

#### *Subjects*

Seventy-five experimentally naive female hooded (Long-Evans derived) rats, from a colony maintained at Syracuse University, were approximately 80 days of age and were housed in individual cages with free access to food and water during the experiment.

#### *Apparatus*

Two Grason-Stadler single-lever operant boxes (Model E 3125A-100) were used. The levers required approximately 12 g (0.12 N) to operate. The boxes were housed in sound-attenuating chambers and ventilated by a fan, which produced a background noise level of 79 dB (SPL). The WS was a 1000-Hz tone, which raised the sound level to 84 dB (SPL). The SS was a 10-Hz flashing light (10 W, clear glass bulb) mounted on the Plexiglas door to the box. A red domed cue light to the left of the lever provided general illumination throughout all sessions; it contained a 10-W 110-V bulb operated on 68 V. Shock was generated by a high-voltage ac source with 260-K $\Omega$  resistance in series with the animal. The intensity, calibrated as in the previous experiments,

was 2 mA and was scrambled by a relay scrambler (Brush, 1967).

*Experimental design.* A simple one-factor randomized design was used. Six groups of nine subjects each were trained with signal-shock intervals of 10, 20, 30, 40, 50, and 60 sec.

#### *Procedure*

The training procedure for all groups was essentially that of the F-10-1 and F-10 groups of Experiments I and II, respectively, with, of course, the appropriate signal-shock interval. However, instead of using a fixed-duration session, 10 trials were given per day for 10 days. To limit total session duration, a 30-min limit on escape latency on each trial was established. Any animal failing to escape within 30 min of the first shock pulse on any trial was eliminated from the experiment. This happened almost without exception during the first 10 trials of training. Additional animals were trained until nine subjects were included in each group; 3, 2, 1, 3, 9, and 3 animals were eliminated from the six groups listed in increasing order of duration of the signal-shock interval.

The latency of the first lever press on each trial was recorded to the nearest 0.1 sec. On each trial, responses during the last 60 sec of the 5-min SS period were recorded to prevent postshock or postavoidance response bursts from inflating response rate during SS.

#### RESULTS

Although a large number of animals were rejected for failure to escape shock in the 50-sec group, this was presumably due to the vicissitudes of sampling, since animals were assigned randomly to each group. This inference was confirmed by a Kolmogorov-Smirnov one-sample test (Siegel, 1956), which was not significant ( $0.15 < p < 0.20$ ).

Figure 3 presents the median per cent avoidance responses for each group for each daily session of 10 trials. Clearly, the 10-sec group performed more poorly than did the other signal-shock interval groups. At intervals between 20 and 60 sec, the acquisition functions were highly similar, with asymptotic performances of 90% being reached within 40 to 50 trials in most cases. A Kruskal-Wallis (Siegel, 1956) one-way analysis of variance of total avoidances in 100 trials confirmed that the effect of duration of the signal-shock interval

was significant,  $H(5) = 14.9$ ,  $p < 0.02$ . A follow-up analysis using only the 20- to 60-sec groups was not significant  $H(4) = 5.2$ ,  $0.2 < p < 0.3$ , suggesting that the overall effect was due to the poor performance of the 10-sec group. This was further confirmed by Mann-Whitney  $U$  tests (Siegel, 1956) of the differences between the 10- and 20-sec groups and between the 10- and 40-sec groups; the former test was significant ( $p < 0.02$ ), although the latter was not.

As in the previous experiments, responses during the SS were infrequent. Based on 1-min samples at the end of each 5-min SS period, median response rates over the 100 trials of training were 0.15, 0.13, 0.27, 0.19, 0.13, and 0.23 responses per minute for the six groups listed in increasing order of signal-shock interval. These rates are comparable to those of corresponding groups in Experiments I and II. Highest group median rates of responding in SS (0.3 to 0.4 responses per minute) typically occurred during the first two or three sessions and diminished to near zero (0 to 0.2 responses per minute) by the last few sessions. The maximum rate for any animal in any session was 2.2 responses per minute in the third session of one animal in the 50-sec group.

Avoidance response latencies were tabulated for each group and cumulative relative frequency distributions of these latencies were calculated. To assess the extent to which animals in each group utilized the available signal-shock interval, various percentiles of these latency distributions were calculated and plotted as functions of the duration of the signal-shock interval. The left panel of Figure 4 presents the fiftieth, seventy-fifth, ninetieth, and ninety-fifth percentiles of the distributions of all avoidance latencies for each group; the diagonal line in the figure is the upper limit of the avoidance latency distribution, *i.e.*, the signal-shock interval. The ninetieth percentile function indicates, for example, that in the 60-sec group, 90% of avoidance responses had latencies of 28 sec or shorter. Thus, only 10% of avoidance latencies in this group were longer than 28 sec and were distributed over the remaining 32 sec of the 60-sec signal-shock interval. Similarly, 95% of avoidances in that group occurred with latencies shorter than 37 sec. Clearly, the longer the signal-shock interval the less completely was the available time utilized, *i.e.*, the avoidance latency distributions are all positively skewed (since 50%



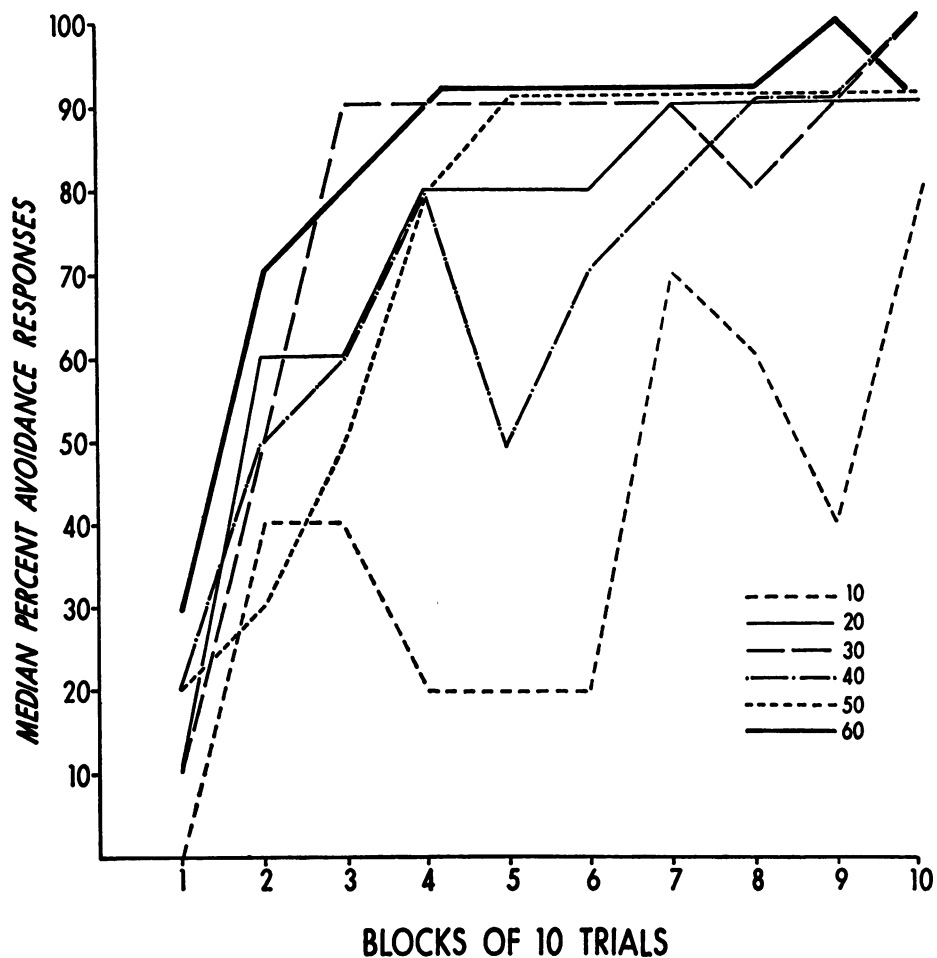


Fig. 3. Median per cent avoidance responses as a function of training sessions in Experiment III.

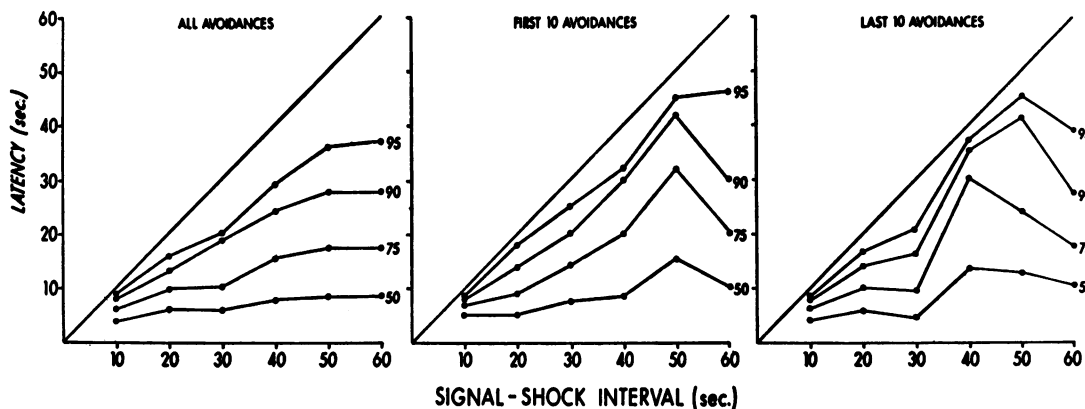


Fig. 4. The fiftieth, seventy-fifth, ninetieth, and ninety-fifth percentiles of the cumulative relative frequency distributions of avoidance response latencies for the entire training session (left panel), first 10 avoidances (middle panel) and last 10 avoidances (right panel) for Experiment III. The latency of the first and last 10 avoidances were tabulated for each animal without regard to the point in training at which they occurred.

of all avoidances in all groups had latencies shorter than 10 sec), and the amount of skewness increases as a function of the duration of the signal-shock interval.

If, as suggested earlier, the greater opportunity to respond afforded by longer signal-shock intervals benefits acquisition by permitting early contact with the avoidance contingency, then the latency distribution of early avoidances should show greater use of the time available than do later avoidances. The middle and right panels of Figure 4 present percentile data, as in the left panel, to describe the group latency distributions of the first 10 and last 10 avoidance responses made by each animal in each group. As for the distribution of all avoidance latencies (left panel), positive skewness, which increases with duration of signal-shock interval, is also characteristic of the latency distributions of the first and last 10 avoidance responses. Note that the fiftieth percentile in all groups is at or below 15 sec. In comparison with the total distributions, the distributions of the first 10 avoidance latencies show somewhat greater use of the available time early in training, since the seventy-fifth to ninety-fifth percentiles of those distributions are above those for the overall frequency distributions. Paradoxically, however, the same thing is true of the distributions of the last 10 avoidances, which virtually overlap those of the first 10 avoidance responses. Wilcoxin matched-pair signed-rank tests (Siegel, 1965) were calculated on the differences between the median latency of the first and last 10 avoidances for each group. Only the 30-sec group showed a significant change, in that case, a decrease from the first to the last 10 avoidances ( $p < 0.02$ ). Taken together, the data presented in the three panels of Figure 4 suggest that avoidance latencies may first decrease and then increase while always remaining positively skewed. Examination of the median latency of successive blocks of 10 avoidance responses indicated that this pattern did occur in some groups, especially the 50-sec group.

#### DISCUSSION

It is clear from the data of this experiment that avoidance performance is directly related to duration of the signal-shock interval. However, the contribution of this variable was complete by 20 sec, since only the 10-sec group

made significantly fewer avoidances in 100 trials than did all the other groups, which did not differ among themselves. The significant effect on performance of increasing the signal-shock interval from 10 to 20 sec is consistent with the effect of this variable reported by Bolles, Warren, and Ostrov (1966). In the present experiment, the duration of signal-shock interval was clearly without effect beyond 20 sec, and performance, although a *monotonic* function, was clearly not a *linear* function of the signal-shock interval.

Bolles *et al.* did not examine intervals longer than 25 sec, and hence could not have detected the nonlinearity of the function. Thus, the prediction that long signal-shock intervals facilitate acquisition simply because of increased opportunity to respond is not supported by our data because the function should be linear if simple probability mechanisms are to account for the facilitatory effect of signal-shock interval.

Furthermore, the analyses of avoidance latency distributions also show that the animals trained with long signal-shock intervals did not fully utilize the time available for avoidance of shock. These distributions, whether for all avoidances or for the first or last 10 avoidances were positively skewed, and the amount of skewness increased with duration of the signal-shock interval, which indicates that as opportunity to respond increased, progressively less use of that opportunity was made. Occasional avoidance latencies that closely approached the limit of the signal-shock interval did occur in all groups. However, their occurrence became less frequent as the interval increased, and they appeared to occur randomly throughout training. Specifically, in the 60-sec group, fewer than 5% of avoidance responses occurred during the last 20 to 25 sec of the signal-shock interval, *i.e.*, the last 33% of the interval was used less than 5% of the time. Thus, the avoidance frequency data and the distribution of avoidance latencies do not support the opportunity to respond interpretation of the effect of signal-shock interval.

However, the early avoidance data do suggest that the longer intervals may allow the animals to contact the avoidance contingency and thus obtain reinforcement for early adventitious avoidances. The latency distributions of the first 10 avoidance responses were some-

what elevated over the total distributions, and thus lend support to this notion. But if this were true, one would expect to see a progressive shortening of avoidance latency over trials as the cumulative effects of reinforcement increase. This expected trend was not observed and, indeed, as many long latencies occurred in the first as in the last 10 avoidance responses. However, the elevation of the percentiles of the first and last 10 avoidance latency distributions may be due in part to the fact that these distributions are based on a smaller sample size and therefore are less stable than are the distributions of all avoidance response latencies. This is particularly apparent in the reversals of the functions around the 40- and 50-sec intervals.

In general, the performance levels obtained in this experiment were superior to those found in comparable groups in Experiments I and II. Although Experiment III was carried out in a different laboratory, the stimulus conditions were quite comparable to those of the first two experiments. A major difference is the strain of animal used, Long-Evans hooded rats in Experiment III *versus* Sprague-Dawley albino rats in Experiments I and II. On the basis of other experiments (*e.g.*, Nakamura and Anderson, 1962) this genetic difference seems likely to provide a bias in favor of superior avoidance behavior in Experiment III. Another factor, however, is that in Experiment III, animals failing to escape shock within 30 min were excluded from the experiment, whereas in the first two experiments no such criterion was used. This would also bias results in favor of superior performance in the third experiment relative to the first two.

### GENERAL DISCUSSION

The primary conclusion to be drawn from the data of these three experiments is that rats can learn a lever-press avoidance response in a discrete-trial procedure with a speed and efficiency comparable to other, formerly more successful, response forms (see Bolles, Stokes, and Younger, 1966; Bower, Starr, and Lazarovitz, 1965; Brush, 1966). Since at least 1960 (*i.e.*, Meyer *et al.*) lever-press avoidance learning has been problematic; learning, where it occurred at all, was slow, and many investigators abandoned efforts to use or study

discrete-trial lever-press avoidance training procedures. Despite its obvious utility in appetitive paradigms, the lever-press response appeared to be uniquely unsuited for discrete-trial aversive conditioning. The situation was so bad that Bolles (1970, 1971, 1972) argued that the avoidance response could be learned only if it was at least highly similar to an SSDR (species-specific defense reaction, *i.e.*—fleeing, freezing, or fighting, in the rat). “Bar-pressing is certainly not an SSDR,” [Bolles, 1970, p. 34]. Similarly, Seligman (1970) argued that there is a continuum of biological preparedness to learn certain associations, to wit: one-trial taste aversion (Garcia and Koelling, 1966; Rozin, 1968) is a cited instance of preparedness and poor lever-press avoidance after thousands of trials (D’Amato and Schiff, 1964) is a cited instance of contrapreparedness. However, no clear conclusion can be drawn from negative findings, since there are many reasons why an animal can fail to respond, and these are difficult to specify. Such *posthoc* interpretations appear to us unwarranted, and they are seriously questioned by the highly successful avoidance learning shown in all three of the present experiments. Thus, it may be premature to challenge the generality of “the” laws of learning on the basis of such negative evidence.

It might well be that an SSDR could be learned even more rapidly than the lever-press response under our training conditions. The fact that parameter values that are highly successful in a two-way shuttle situation are patently unsuccessful when applied to the lever-press response clearly indicates a strong interaction between response form and training parameters. The available data from shuttle-box experiments with rats show that although the 5-min safe period would facilitate avoidance learning (Brush, 1962), there is evidence that shuttle-box avoidance learning would be unsuccessful under the present experimental conditions. Levine (1966) and Moyer and Korn (1964) showed that shuttle-box avoidance learning is inversely related to shock intensity. The latter study showed poor acquisition at intensities greater than 1.5 mA, and the former showed impeded learning at levels above 0.5 mA. We found successful avoidance learning with 2.0 mA. Furthermore, Black (1963) showed that speed of acquisition of shuttle-box avoidance learning

was a nonlinear function of the CS-US interval using a delayed conditioning procedure with rats. He tested the effects of 5-, 10-, 20-, and 30-sec intervals and found the fastest acquisition at 10 sec. These data suggest that shuttle-box avoidance learning would be poor with signal-shock intervals above 20 sec, at which we obtained such excellent performance. Previous reports of failure to obtain rapid lever-press avoidance learning used short signal-shock intervals that are clearly more appropriate for the shuttle response (e.g., Meyer *et al.*, 1960).

We noted above that the opportunity-to-respond interpretation of the effect of signal-shock interval is not an adequate one for the following reasons: (1) the effect of increasing the duration of the interval is nonlinear with no further facilitation of learning beyond 20 sec; (2) the avoidance response at all intervals comes under good stimulus control early in training, so that we are not dealing with a high rate of nondiscriminated lever pressing; (3) the avoidance latency distributions are positively skewed, a property that increases with duration of the signal-shock interval, so that little use is made of the "greater opportunity" afforded by the long intervals; (4) the similarity of early and late avoidance latency distributions and the lack of a progressive decrease in avoidance latency over trials argues against the notion that long intervals permit early contact with the avoidance contingencies, and hence earlier reinforcement of the avoidance response. Thus, an alternative interpretation of the effect of signal-shock interval is needed.

Something unique appears to happen if the signal-shock interval is as short as 10 sec, despite the fact that rats can, and frequently do, respond with latencies under 10 sec. Note again that the median latency of all avoidance responses was under 10 sec in all groups of Experiment III. Rather than view the effect of signal-shock interval in terms of the unsupported notion of opportunity to respond, whether that is taken to mean a learning or a performance effect, it is perhaps more defensible to say that when the interval is limited to 10 sec, rats perform poorly, perhaps because an active interfering process occurs with intervals that short. We would suggest that freezing responses, which compete with the active lever-press response (see Hoffman, 1966), might be established with a 10-sec interval, but less

strongly so with intervals 20-sec or more in duration. This suggestion may be consistent with the observation of Maier, Albin, and Testa (1973) that "learned helplessness" occurs in rats only when the escape response is learned slowly, as was the case in these experiments. Thus, although the avoidance contingency is present in the 10-sec groups, it appears that in failing to make contact with that contingency during the initial sessions an effect similar to that of uncontrollable shock could occur, thus interfering with active avoidance learning. This idea is clearly speculative at this time, but it is subject to experimental test.

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