*FREE-OPERANT ESCAPE-AVOIDANCE OF NOISE BY RATS*¹JOHN F. KNUTSON AND MARGARET I. BAILEY²

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A series of experiments was conducted to establish free-operant escape-avoidance responding in rats using noise as the stimulus. Naive rats did not acquire a bar-press response on an escape-avoidance of noise schedule. Similarly, free-operant responding established using escape-avoidance of shock was not maintained when noise was substituted for shock. Noise stimuli of 110 dB did maintain responding, but at a lower level than during training, when the noise stimuli had first been paired with shock. Noise stimuli of 97 dB and 87 dB were not effective under those same conditions. Additional rats were trained on a free-operant escape-avoidance schedule of shock and then exposed to a delayed conditioning procedure in which noise was the conditioned stimulus and shock was the unconditioned stimulus. When these subjects were then tested with noise alone, two of the three subjects conditioned and tested with 105-dB noise displayed escape-avoidance of noise, but none of the rats conditioned and tested at 97 dB displayed escape-avoidance of noise. The results suggest that free-operant escape-avoidance of noise can be demonstrated; however, only higher intensity noise stimuli that have been paired with shock are effective.

The free-operant avoidance procedure (Sidman, 1953) has had important implications for analyses of aversive control of behavior (*e.g.*, Anger, 1963; Church and Getty, 1972; Herrnstein and Hineline, 1966); however, the generality of the procedure is somewhat attenuated by the limited array of stimuli used. The free-operant avoidance literature reflects extensive consideration of electric shock and some limited explorations of timeout from positive reinforcement (*e.g.*, D'Andrea, 1971; Thomas, 1965*a*, 1965*b*). In order to extend this procedure, it seems reasonable to assess its efficacy using stimuli other than electric shock.

Campbell and Bloom (1965) demonstrated that noise is mildly aversive, as compared to electric shock. Although free-operant avoidance of noise has not been reported, escape behavior has been generated using noise stimuli (*e.g.*, Barnes and Kish, 1957; Campbell and

Bloom, 1965; Halpern and Lyon, 1966; Harrison and Abelson, 1959). Such data suggest that noise might be a viable candidate as an alternative to shock in a free-operant avoidance procedure. The following experiments were attempts to produce free-operant escape-avoidance of noise stimuli.

Experiments Ia and Ib determined whether naive rats would acquire and maintain a bar-press response under free-operant escape-avoidance conditions when 110-dB noise was used as the aversive stimulus.

EXPERIMENT Ia

Subjects

Twelve experimentally naive 103- to 111-day-old, male hooded rats served; six were randomly assigned to the noise condition and six to the shock condition. All rats of this and of subsequent experiments were housed individually, with food and water continuously available.

Apparatus

The test chamber was a 12 by 9.25 by 7.5 in. (30.5 by 23.7 by 18.8 cm) Plexiglas box with a grid floor constructed of 0.093 in. (2.4 mm) diameter stainless steel bars spaced 0.5 in. (1.27 cm) center to center. A 5-cm wide Ger-

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brands lever was mounted on one wall, 2.5 in. (6.3 cm) above the grid and protruding 1 cm into the chamber. A force of approximately 20 g (0.19 N) on the bar was required to actuate a switch. The box was housed in a lighted, sound-attenuated chamber. An exhaust fan provided ventilation and masking noise. The ambient noise level in the center of the chamber, with the head of the microphone 2 in. (5 cm) above the grid floor, was 78 dB, measured by a General Radio Model 1551C sound-level meter set to ASA standard frequency response curve "C". All subsequent noise-intensity measurements, and the setting of noise levels, were made in this manner. Variation in noise level as a function of altered microphone placement never exceeded 3 dB. The 0.8-mA shock, which was provided to the grid floor by a tube-type constant-current dc source, was scrambled through a Gerbrands Model G5820 scrambler. Noise was generated using an unfiltered zener-diode circuit, amplified through a Thoradson Model T-30W55 amplifier, and supplied to the experimental chamber by two Olsen Electronics 4-in. (10 cm) X-air speakers located directly on the top of the test chamber. Analysis of the noise, by means of a Hewlett Packard Model 302-A wave analyzer and a General Radio Type 1521A Graphic Level Recorder, indicated that the sound level was uniform from 600 Hz to 6K Hz; however, a linear decrement in sound level was detected from 6K Hz to 20K Hz. This decrement reached a maximum of 20 dB at 20K Hz. Experimental contingencies were arranged with conventional timers and relay circuitry, and data were recorded with cumulative recorders and electro-mechanical counters.

Procedure

Each rat of the shock group was submitted to a single 12-hr session of a free-operant escape-avoidance schedule consisting of a shock-shock (SS) interval of 2 sec (onset to onset), a response-shock (RS) interval of 10 sec, and a shock duration of 0.5 sec. Responding during shock terminated the shock and initiated the RS interval. The first session was followed by two daily 1-hr sessions.

Rats assigned to the noise escape-avoidance group were exposed to the same schedule, but 110-dB noise was used instead of shock. Monitoring of the noise with a Tektronix Model R5618 dual trace oscilloscope did not reveal

any transient peaks in the noise level during the 0.5-sec intervals.

RESULTS

None of the six rats in the noise condition displayed more than a few bar-press responses. Response rates of individual subjects ranged from 0.003 to 0.133 responses per minute in the 12-hr session, and from 0 to 0.133 per minute in the two 1-hr test sessions. These response rates resulted in avoidance of no more than 3% of the maximum scheduled noise presentations.

In contrast, only two of the six rats in the shock condition failed to display sustained bar-press responding. The four rats that did acquire the response displayed overall response rates ranging from 2.5 to 12.3 responses per minute during the 12-hr session. Three of those four rats displayed few responses during the first several hours of the session, but their response rates gradually increased during the latter part of the session. During successive hours of the session, rates of responding of individual subjects ranged from 0 to 3.0 per minute during initial hours, and ranged from 6 to 14.5 responses per minute during the last 2 hr of the session. The rat that acquired the response within the first hour of the 12-hr session displayed a gradual increase in rate early in the session, followed by stable responding throughout the remainder of the session. The four rats responded at overall rates ranging from 8.5 to 12.5 responses per minute during the next two sessions, and avoided 76 to 87% of the maximum scheduled shocks, calculated on the basis of the SS interval.

EXPERIMENT Ib

Following the failure of any of the subjects in the noise condition to acquire the escape-avoidance response in Experiment Ia, an alternative procedure, using shaping by the method of reinforcement of successive approximations, was attempted.

Subjects

Subjects in the noise condition were six experimentally naive 90- to 113-day-old, female hooded rats. The performance of these rats was contrasted with thirty six, 85- to 120-day old, female hooded rats that had been submitted to escape-avoidance of 0.8-mA shock under the

same training conditions and the same SS, RS, and shock duration intervals used in the noise condition.

Apparatus

The apparatus used in Experiment Ia was employed.

Procedure

Rats were given five to 20 daily 30-min sessions consisting of the escape-avoidance schedule used in Experiment Ia. An observer initiated the response-noise (RN) interval when the locus of the animal's behavior was close to the manipulandum. Gradually, approximations of bar-press behavior were required before the response-noise interval was started.

RESULTS

Five of the six subjects exposed to the noise schedule failed to press the bar. One rat displayed some bar-press responding, which was maintained for two sessions at a mean overall rate of 0.7 responses per minute. This performance resulted in very little avoidance of noise. The characteristic response displayed by the other rats was freezing.

The noise data may be compared with the behavior of animals exposed to the same contingencies using a 0.8-mA electric shock. All subjects acquired the response by the second session, and many evidenced rates exceeding six responses per minute by the end of the first shaping session. Unlike the noise subjects, locomotion was the characteristic response to the stimulus.

EXPERIMENT II

Experiments Ia and Ib suggested that a 110-dB noise stimulus was not sufficiently aversive to establish free-operand escape-avoidance responding. This experiment determined whether free-operand escape-avoidance established with a compound stimulus (noise and shock) would be maintained using only noise. In addition, the experiment determined whether the intensity of the noise influenced maintenance of the behavior.

METHOD

Subjects

Ten experimentally naive 90- to 112-day-old, female hooded rats were used; four were ran-

domly assigned to the 110-dB condition, three to the 97-dB condition, and three to the 87-dB condition.

Apparatus

The apparatus was the same as that used in Experiments Ia and Ib. In addition, the manipulandum was wired in parallel with the grid floor to provide scrambled shock to the bar.

Procedure

Responses were shaped on a schedule of free-operand escape-avoidance of a compound stimulus. The compound stimulus consisted of a 0.8-mA shock paired simultaneously with either 87-, 97-, or 110-dB noise, depending upon group assignment. The RS interval was 10 sec, the SS interval was 2 sec, and stimulus duration was 0.5 sec. The simultaneity of the components of the compound stimulus was assessed using an oscilloscope.

After the bar-press response was established, all subjects were submitted to at least 15 daily 30-min sessions of a baseline consisting of free-operand escape-avoidance of the compound stimulus. The conditions were then changed for at least five sessions to free-operand escape-avoidance of noise using the same schedule parameters. The noise intensity for each subject was the same as during acquisition and baseline. Subsequently, the subjects were returned to the compound stimulus baseline for at least five sessions, resubmitted to the escape-avoidance of noise condition for at least five sessions, and again returned to the compound stimulus baseline. Then, all subjects were given five, 30-min sessions of a no-stimulation extinction schedule to assess the posttraining operant level. In addition, Subject D, from the 110-dB group, was returned to the baseline schedule and then given 16 additional daily sessions of the escape-avoidance of noise schedule and seven additional sessions of extinction.

RESULTS

Figures 1 and 2 show the response rates for each rat under each schedule condition. All rats acquired the bar-press response with 30 to 90 min of shaping. By the later sessions of baseline, all rats displayed a moderate to high rate of escape-avoidance responding, which was associated with the avoidance of at least 78% of the scheduled stimulus presentations. When

shifted to the noise condition, all rats showed a marked decrease in response rate. However, when this rate decrease is compared with the rate decrease during extinction, differences among the noise-intensity groups are apparent. The rats exposed to the 110-dB noise (Figure 1) responded at a higher rate than during extinction, and this responding was sustained across all such sessions. Individual rats avoided as much as 68 to 75% of the scheduled noise presentations during the higher rate sessions, and as few as 22 to 59% during sessions of low-rate responding. During extended exposure to the noise condition, Rat D continued to respond for 16 successive sessions. Only Rat E (Figure 2), tested at 97 dB, displayed escape-avoidance of noise. However, the behavior of that rat exceeded extinction performance during the first series of noise test sessions only and this performance was never associated with

more than 28% avoidance. The other rats tested with 97-dB noise, and all rats tested with 87-dB noise (Figure 2), displayed response rates during the noise sessions that were indistinguishable from those during extinction, and those rates resulted in no more than 5% avoidance.

Figure 3 shows representative cumulative records of the bar-press responding of the four rats of the 110-dB group. These records reflect the characteristic performance differences among the three schedule conditions. The most obvious differences are seen in overall rates of responding. In addition, the responding during escape-avoidance of noise was much more irregular, containing prolonged periods of high-density stimulation without bar pressing. The absence of responding during the initial minutes of the noise records (Rats A and D) was evident in the performance of all subjects

Fig. 1. Overall response rates displayed during escape-avoidance of the compound stimulus, escape-avoidance of the noise stimulus, and during extinction by the rats of Experiment II trained and tested using 110-dB noise.

Fig. 2. Overall response rates displayed during escape-avoidance of the compound stimulus, escape-avoidance of the noise stimulus, and during extinction by the rats of Experiment II trained and tested using 87-dB (H, I, J) and 97-dB (E, F, G) noise.

Fig. 3. Representative individual session cumulative records produced by the four rats of Experiment II trained and tested using 110-dB noise. The letters identify the individual subjects. The numbers associated with each cumulative record identify the number of the session. These numbers correspond to session numbers of Figure 1.

in the 110-dB group during much of the exposure to the noise condition. Figure 4 summarizes the mean percentage of responses during successive quarters of sessions for the blocks of sessions of escape-avoidance of noise and escape-avoidance of the compound stimulus (baseline). Figure 4 reflects the general pattern of increased responding as a function of time in the session during escape-avoidance of noise. Although the magnitude of this pattern is variable, the only departure was Rat D during the second block of noise test sessions.

EXPERIMENT III

This experiment was undertaken as a follow-up to Experiment II, to determine whether responding established under a free-operant escape-avoidance schedule using only electric shock would be maintained under the same schedule using an intense noise stimulus.

Subjects

Three 94-day-old, experimentally naive female hooded rats were used.

Apparatus

The apparatus was similar to that used in Experiment II, differing only in overall dimensions. This test chamber was 14 by 8.3 by 8.5 in. (18.4 by 35.3 by 21.1 cm) and was used because of concurrent scheduling problems associated with the other chamber. The chamber was housed in a lighted, sound-attenuated enclosure identical to the one used in the previous experiment. The ambient noise level in the center of the test chamber was 74 dB. As in the previous experiments, noise was supplied to the test chamber by two Olsen Electronics 4 in. (10 cm) X-air speakers located directly on top of the test chamber. The rest of the apparatus was identical to that used in the previous experiments.

Procedure

Following shaping, all rats had 15 daily 30-min sessions of a free-operant escape-avoidance schedule consisting of the same RS interval, SS interval, and shock duration and intensity used in the previous experiments. A 105-dB noise was used in place of the electric shock in alternate blocks of five sessions for the next 20 sessions. Finally, there were five extinction sessions with neither shock nor noise.

Fig. 4. The mean percentage of responses within successive quarters of sessions for the four subjects of Experiment II that were trained and tested with 110-dB noise. Letters identify each subject. The distributions are based on the block of five baseline sessions immediately preceding the first test of escape-avoidance of noise, and successive blocks of escape-avoidance of noise, and baseline. These distributions are ordered chronologically from left to right on the abscissa, consistent with Figure 1.

RESULTS

Figure 5 shows the overall response rates for each session for each rat in Experiment III. This figure demonstrates that all three subjects rapidly acquired the bar-press response and maintained the behavior under the escape-avoidance of shock schedule. However, responding during the noise schedule was negligible and could not be distinguished from responding during extinction.

DISCUSSION

Since 105-dB noise was not an effective stimulus for the maintenance of free-operant escape-avoidance responding established and maintained with shock, it is possible that the results of Experiment II were a function of a higher intensity (110-dB) noise, or the exposure to both shock and noise during training. The former alternative relates responding to the intensity of the noise stimulus. The latter suggests that the noise, by being paired with shocks during training, became a conditioned

aversive stimulus, and that the responding during noise reflected free-operant escape-avoidance of a conditioned aversive stimulus. This second hypothesis is weakened by the finding that the 97-dB and 87-dB noise stimuli were also paired with shock and they were not avoided during the noise-only tests. Two experiments were conducted to assess the possibility that the escape-avoidance responding by the 110-dB animals was a function of the pairing of shock and noise.

EXPERIMENT IV

To determine whether all noise levels of Experiment II could have functioned as conditioned stimuli, this experiment assessed whether the rats of Experiment II could discriminate the noise stimuli from the ambient noise level.

Subjects

The subjects of Experiment II, except Rat B, served; Rat B died between experiments.

Apparatus

The apparatus was the same as in Experiment II.

Procedure

Each rat was given daily 30-min sessions of a discriminated avoidance schedule consisting of a 3-sec discriminative stimulus followed immediately by a 0.5-sec duration 0.8-mA electric shock. Discriminative stimulus presentations were scheduled at irregular intervals averaging 30 sec, following the Fleshler and Hoffman (1962) progression. Responding during the discriminative stimulus terminated the discriminative stimulus and avoided the subsequent shock. Responding during shock and during the interstimulus interval had no consequence. Discriminative stimuli were either 110-, 97-, or 87-dB noise. For each rat, the discriminative stimulus was the same noise stimulus used during Experiment II.

RESULTS

In fewer than 20 sessions, all nine rats avoided more than 50% of the scheduled shocks, and six of these rats regularly avoided more than 85% of the shocks. Two of the less-efficient subjects were from the 97-dB group and one was from the 87-dB group. During the

discriminative stimulus, these less-efficient subjects often moved to the bar and adopted a position on the bar, but responding did not occur until shock onset. Responding during shock and immediately after shock offset, which was characteristic of the behavior during the free-operant escape-avoidance of shock schedule, was continued by all rats during these

Fig. 5. Overall response rates of each rat in Experiment III during escape-avoidance of shock, during escape-avoidance of 105-dB noise, and during extinction.

sessions. During the later sessions, response rates during the discriminative stimulus ranged from 9.6 to 18.3 responses per minute. Responding during the intertrial interval was usually less than one response per minute, although bursts of postshock responding occasionally resulted in overall rates as high as 3.6 responses per minute. Although the postshock bar pressing persisted, the data still indicated the rats could discriminate all three noise stimuli from the ambient noise level.

EXPERIMENT V

To amplify the results of Experiment II, this experiment determined whether a noise stimulus that was paired with shock in a Pavlovian conditioning procedure would maintain free-operant escape-avoidance behavior previously established with shock used as the stimulus.

Subjects

Six 93- to 109-day-old, experimentally naive female hooded rats served.

Apparatus

The apparatus was the same as that used in Experiment III, with the addition of a 9.5 by 12.75 by 8 in. (24 by 32 by 20 cm) Plexiglas conditioning box that could replace the escape-avoidance chamber on the grid floor.

Procedure

Bar-press responding was shaped on the escape-avoidance of shock schedule used in the previous experiments. Responding was maintained on the escape-avoidance of shock schedule for 12 to 16 daily 30-min sessions. Each rat was then exposed to two 30-min sessions of a delayed conditioning procedure. Trials consisted of a 1-sec conditioned stimulus (CS) followed immediately by a 0.5-sec unconditioned stimulus (0.8-mA shock). Varying intertrial intervals, with a mean of 36 sec, were scheduled following the Flesher and Hoffman (1962) progression. Three rats experienced 105-dB noise as the CS and three rats experienced 97-dB noise as the CS.

After two delay conditioning sessions, the rats were given five sessions of the same escape-avoidance schedule used before conditioning, but the CS used during conditioning was substituted for shock. The rats then were given five additional sessions of the escape-avoidance of shock schedule and then five sessions of a no-stimulation extinction procedure.

RESULTS

Figure 6 shows the overall rates of responding during escape-avoidance of shock, escape-avoidance of noise, and extinction. Two of the rats (PA and PB), conditioned and tested at 105-dB, responded during escape-avoidance of noise at a rate that differed from extinction. The third 105-dB rat (PC), and the three rats

conditioned and tested at 97 dB, responded during the sessions of escape-avoidance of noise in a manner that did not differ from extinction. Examination of the cumulative records of these subjects also indicated that only Subjects PA and PB responded during escape-avoidance of noise, and this responding was associated with the avoidance of 41 to 68% of the scheduled occurrences of noise. The remaining four rats responded during escape-avoidance of noise as they responded during extinction sessions, and this responding was associated with the avoidance of no more than 10% of the scheduled noise. Figure 7 shows representative cumulative records of the two 105-dB rats that responded during escape-avoidance of noise. The responding during noise was characterized by increased responding during the later parts of the sessions. This pattern is also reflected in Figure 8, which gives the mean percentage of responses occurring in successive quarters of sessions.

GENERAL DISCUSSION

The inability to establish behavior control with the noise stimuli used in Experiments Ia and Ib underscores the Myers (1967) contention that the evidence for aversion to auditory stimuli is a function of the test methods. That is, stimuli reported to be aversive under locomotor escape conditions (*e.g.*, Campbell, 1957) did not maintain bar-press free-operant escape-avoidance behavior of rats in Experiments Ia and Ib.

Escape-avoidance behavior was obtained only when the louder (110 dB and 105 dB) noise intensities were used, when those noise stimuli had been previously paired with shock, and when the subjects had been conditioned to bar press on the free-operant schedules. These results suggest that intense noise stimuli that are conditioned aversive stimuli will maintain free-operant escape-avoidance behavior. Several aspects of these experiments suggest that neither the intensity of the stimulus nor conditioned aversion alone account for the effects. Since 110-dB noise was ineffective without being paired with shock, intensity alone is not enough. Responding at the higher noise level cannot be attributed to an elicitation effect of high noise, since response rate and per cent avoidance were lower when the same noise had not been paired with shock. Similarly, two

Fig. 6. Overall response rates of individual rats in Experiment V during free-operant escape-avoidance of shock and free-operant escape-avoidance of noise following a delay conditioning procedure. PA, PB, and PC were tested with 105-dB noise and PD, PE, and PF were tested at 97 dB.

aspects of the data suggest that conditioning *per se* was not enough to maintain the behavior. First, the 87-dB and 97-dB noise levels of Experiment II, although discriminable (Experiment IV), were not effective as conditioned aversive stimuli in maintaining the behavior. Similarly, the 97-dB stimulus did not maintain the behavior after being paired with shock in the delayed conditioning procedure

of Experiment V. While the acquisition of a conditioned response to noise stimuli in a delayed conditioning procedure may be a function of the intensity of the stimulus (Kamin and Schaub, 1963), even the lowest level used in this study exceeded the highest level reported in the Kamin and Schaub (1963) research. Thus, this failure to obtain responding to 87-dB and 97-dB noise is not likely a

Fig. 7. Representative cumulative records of two of the rats trained and tested with 105-dB noise during Experiment V. The letters identify the individual subjects, and the numbers identify the number of the session.

Fig. 8. The mean percentage of responses within successive quarters of sessions for the two subjects of Experiment V that evidenced responding during escape-avoidance of noise. The distributions are based upon the block of five sessions of escape-avoidance immediately preceding the delayed conditioning procedure, the block of five sessions of escape-avoidance of noise, and the block of five sessions following escape-avoidance of noise. These distributions are ordered chronologically from left to right on the abscissa, consistent with Figure 6.

function of using CS intensities inadequate for classical aversive conditioning.

The second aspect of the data that points to the inadequacy of a simple conditioned aversion account is the within-session “warm-up” effect. If the escape-avoidance behavior were due only to conditioned aversion, the opposite pattern would be expected as stimuli gradually lose their conditioned effects. Thus, these data suggest that stimulus intensity and conditioned aversion are both necessary for the free-operant escape-avoidance of noise obtained in the present study. Future research could profitably explore the boundary conditions of the auditory stimulus characteristics (*e.g.*, intensity and frequency) and conditioning procedures necessary for the phenomenon. The function determining the manner in which conditioning and stimulus intensity combine to control the escape-avoidance behavior cannot be ascertained from these data, and a parametric exploration seems necessary.

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