ESCAPE BEHAVIOR UNDER DIFFERENT FIXED RATIOS AND SHOCK INTENSITIES¹

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The effects of ratio length and shock intensity on bar pressing were examined in three rats in two escape-from-shock experiments. In Experiment I, shock intensity was held constant while the schedule was varied from FR 1 to FR 20. The latency of the first escape response increased with FR length while the escape rate, computed as over-all rate in shock minus latency of the first response, decreased at FR 20. In Experiment II, the schedule was held constant at FR 5 while shock intensity was manipulated. Latency decreased as intensity increased, while escape rate increased with intensity, passing through a maximum for two subjects. Responses occurring during the last 100 sec of the 2-min escape period decreased as the FR increased for all subjects, and decreased as shock intensity increased for two subjects.

A recurrent concern in the literature on escape behavior (Campbell and Kraeling, 1953; Bower, 1960) has been to what extent escape behavior displays properties comparable to behavior maintained by positive reinforcement. It is thus not surprising that many students of escape behavior (Keller, 1941; Kaplan, 1952) have manipulated schedules of reinforcement whose effects on behavior maintained by positive reinforcement are well documented. Application of fixed ratio schedules to the escape case has been made by Kaplan (1956) with bright light as the aversive stimulus. His subjects displayed the break-run pattern which usually characterizes FR performance (Keller and Schoenfeld, 1950; Ferster and Skinner, 1957) under nutritive reinforcement, with the latency of the first escape response an increasing function of ratio length. Investigators who have studied FR escape responding in the presence of electric shock, however, report findings at variance with those of Kaplan. In one of these studies (Weiss and Laties, 1959), the procedure was complicated by the use of a titration schedule in which the terminal response of an FR run yielded a reduction rather than a termination of shock. A recent

study by Hendry and Hendry (1963), reported after completion of the present study, failed to find stable behavior on FR schedules based on escape from shock. The first of the two experiments reported here was an attempt to investigate the effects of different FR lengths on escape-from-shock behavior with a design based on that of Kaplan (1956).

The second experiment investigated the relation between response rate and shock intensity with ratio length held constant. Keller (1941) and Kaplan (1952) have shown in studies with light as the aversive stimulus and fixed interval schedules of reinforcement that response rate first rises with stimulus intensity and then declines at higher intensities. On the basis of data collected with light, white noise, and electric shock, several investigators (Kaplan, 1957; Barry and Harrison, 1957; Boren, Sidman, and Herrnstein, 1959) have suggested that the relationship between escape responding and aversive stimulus intensity depends upon the reinforcement schedule in effect. The second part of the present study provides data bearing on this question in the FR case.

METHOD

Subjects

The same three male albino rats, R4, R7, and R15, were used in both experiments. They were approximately 150 days old at the start of the first experiment and had been used briefly in a food-reward bar-pressing situation under continuous reinforcement about two

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months before the present study. Food and water were available at all times except during experimental sessions. Their bodies were regularly completely shaved with an electric clipper to prevent utilization of body hair as insulation from the current.

Apparatus

A single experimental chamber served for all three subjects. It was 5.875 in. wide, 10 in. long, and 6.75 in. high with a hinged Plexiglas top. The flooring was composed of five brass tubes of 0.625 in. diameter spaced at 1.125 in. from center to center and placed longitudinally in the box. Each of these tubes served as a shock electrode, while the four aluminum walls and the bar served as the sixth electrode. At one end of the apparatus, 3 in. from the grid floor, an aluminum lever 2.5 in. wide and 0.375 in. in diameter was fitted to a Switchcraft Lev-R type switch, as described by Verhave (1958). A pressure of 60 g was required to depress the lever and thereby activate the control and recording equipment. The rather high effort requirement was chosen in view of the large amounts of bar-holding previously observed in escape experiments. The high response rates obtained in pilot work and in the data that follow indicate that the effort requirement of 60 g was not too great for the subjects.

The experimental box was housed in a light-proof J. C. Higgins picnic box equipped with an air blower. White noise masked extraneous sounds.

The shock source was a Grason-Stadler E1064GS shock generator and scrambler which provides alternating current shock with manually adjustable intensities. All intensities referred to in this report specify dial settings in milliamperes. The experimental contingencies were programmed automatically by a system of relays and timers. Latencies were cumulated over each session on a running time meter.

Procedure

Experiment I. Throughout the first experiment, except for R4 as noted below, the shock generator was set at 0.8 ma. This value was selected for behavioral stability on the basis of exploratory work with other rats whose behavior was mainly observed on variable-interval schedules. Each session consisted of 50

trials in which shock was terminated when the rat pressed the bar. The shock returned 2-min later independently of the subject's behavior. If the subject was holding the bar down at the onset of shock, it had to release it and press it again to escape from the shock. With few exceptions, each subject was run at the same time every day of the week. In expectation of variability at the start of the session, two warm-up trials were given before the regular session started and the data from these two trials were not recorded.

After 16 sessions at FR 1, the subjects were successively moved up to FR 5, FR 10, and FR 20. Table 1 presents the programs followed for each subject. Since longer ratios can only

Table 1
Number of Sessions at Each Ratio in Experiment I for Each Subject. Shock intensity was 0.8 ma except where otherwise indicated.

	R15	R7	R4
FR 1	16	16	16; 2*
FR 5	8	13	2*
FR 10	13	9	2*
FR 20	13	13	2*
FR 20 redet.	—	—	2*
FR 10 redet.	—	3	2*
FR 5 redet.	3	2	2*
FR 1 redet.	2	3	2*

*Sessions at 1.6 ma.

be reached by prior training at lower values, an ascending order of ratio requirements had to be employed. However, as shown in Table 1, some data were redetermined after completion of FR 20, after Boren (1953) and Kaplan (1956). The redetermination data were obtained in descending order of ratio length. Redetermination data were obtained directly upon completion of FR 20 for R7 and R4, and only after completion of Exp II for R15. Circumstances forced a somewhat altered procedure in the case of R4, as is seen in Table 1. When placed on FR 5, this subject developed postural reactions which almost completely replaced bar pressing. The shock level was then doubled to 1.6 ma and the subject resumed bar pressing. The only criterion used before shifting to the next ratio for R15 and R7 was that five consecutive sessions occurred in which no competing behavior such as freezing or bar straddling became dominant. The first few sessions at longer ratios usually showed some such disruption of bar pressing.

Experiment II. In this portion of the study, the ratio requirement was held constant at five responses while the shock intensity was systematically varied between zero and 4.0 ma.

Fifteen days intervened between the completion of Exp I and the start of Exp II. The same three rats served as subjects in the same apparatus. Before any data were gathered, each rat was observed for one session of 50 trials on FR 5 at the intensity used in Exp I (0.8 ma for R15 and R7; 1.6 ma for R4). Thereafter, five warm-up trials at that intensity were given each day from which the data were discarded. Each day, data from a 3- to 4-hr session were obtained from two subjects. Each animal was used in two of every three days until it had completed eight sessions. Subjects were tested at all shock intensities (zero, 0.25, 0.5, 1.0, 2.0, and 4.0 ma) in a given session. This procedure was adopted, in part, because of the finding by Dinsmoor and Winograd (1958) that changes in rate of response on a VI 30-sec escape schedule were immediate upon introduction of a new shock intensity. Subjects were presented with shocks of a given intensity for 15-20 trials, after which the shock was either increased to the next higher intensity or decreased to the next lower intensity. Ascending and descending intensity orders were used in alternate sessions. At the lower intensities, it was found that the rate of response was too low to complete 15 trials within a reasonable time, if at all. In such cases, transitions to the next intensity were made after 35 min rather than 15 trials.

RESULTS

Experiment I

Behavior in shock. Bar-pressing in the presence of shock showed the general features of FR behavior pointed out by many investigators (Boren, 1953; Ferster and Skinner, 1957). Performance was characterized by a brief pause before the FR was initiated, then a rapid series of responses until the shock was terminated. For analysis, responding was therefore separated into two measures: the latency of the first response after shock onset, and the rate from the first response to the completion of the ratio. For R15 and R7 the mean latency for each of the last five sessions was computed and the median of these values is plotted as a function of FR length in Fig. 1.

Fig. 1. Median average latency for the last five sessions at each ratio for R7 and R15 and the mean latency of two sessions at each ratio for R4. Unconnected points represent redetermination data.

As indicated previously, R4 ceased responding at FR 5 and data were obtained at 1.6 ma with only two sessions at each ratio. The mean latency of these two days is plotted in Fig. 1 for R4. The square for R4 represents the median average latency of the last five sessions on FR 1 at 0.8 ma (R4 did not stop responding at 0.8 ma until FR 5) and is comparable to that point on the curves of the other two subjects. The unconnected points on all three functions represent redetermination points.

All three curves indicate that the latency of the first escape response increases with increasing ratio length. This finding agrees with the data of Kaplan (1956) who studied FR escape from light in the rat, and with the data of Boren (1953) and Ferster and Skinner (1957) with FR positive reinforcement in the rat and pigeon, respectively. Boren's data showed that although redetermination points followed the trend of the original data, they were much higher overall. In the present case, only R15's redetermined points show this elevation, while all the redetermined points recapture the trend of the initial data. It should be pointed

out that the rise in latencies with greater ratios is not attributable to a few exceptionally long latencies. Inspection of the cumulative response curves for criterion days showed no instance of a latency greater than 12 sec, the shortest latency that could reliably be measured in this manner.

The escape rate, defined as the rate of response between the first and the terminal responses in the ratio run, is plotted as a function of ratio size for each subject in Fig. 2. Obviously, there is no such measure possible at FR 1. No simple function common to the three subjects is apparent in Fig. 2. The individual functions, though differing from each other somewhat, display individual reliability when the redetermination points are examined. Also, for each subject the rate at FR 20 is lower than the rate at FR 5. Examination of the cumulative response curves indicates that the differences in rate might be attributable to breaks occurring after the ratio run is under way. These breaks occurred at FR 20 for all subjects and at both FR 10 and FR 20 for R7. A sample cumulative record from R7 is shown in Fig. 3 with the breaks in responding indicated by arrows. These pauses have been called "strain" by other investigators (Boren, 1953; Ferster and Skinner, 1957) and have been observed at high ratios or in cases where a large increment has been added to a ratio requirement. The slopes in Fig. 3 suggest tentatively that the rates when responding are similar for the different ratios, aside from the occasional break. The validity of this interpretation necessarily hinges upon a breakdown of IRTs which, unfortunately, is lacking.

Behavior during shock-off periods. Holding the bar down for long periods between trials has been commonly observed in escape studies

Fig. 2. Median average escape rate for the last five sessions at each ratio for R7 and R15 and the mean average escape rate for two sessions at each ratio for R4. Unconnected points represent redetermination data.

in which a continuous reinforcement schedule has been employed (Keller, 1941; Dinsmoor and Hughes, 1956; Dinsmoor, Matsuoka, and Winograd, 1958; Migler, 1963). In the present study, the amount of shock-off time spent holding for R15 and R4 decreased to less than 4% by the sixteenth session of FR 1 and never increased above 4% for the rest of Exp I. While R4 was still holding the bar down about 20% of the shock-off time after 16 ses-

Fig. 3. Samples of the cumulative records from R7 at each ratio. The recorder operated continuously during both shock and shock-off periods. Shock termination is indicated by diagonal pips, each of which is followed by 2 min in which the shock is off.

sions on FR 1, holding time for this subject dropped to 2% or less immediately upon the transition to FR 5 and remained in that vicinity thereafter.

A tally by 20-sec periods was kept of those responses occurring during the 2-min shock-off periods. These responses, usually termed "extras", have been reported by many earlier investigators, among them Keller (1941) and Kaplan (1956) in experiments using light as the aversive stimulus, and Dinsmoor, Hughes, and Matsuoka (1958) and Dinsmoor and Clayton (1963), using shock. Keller (1941) and Dinsmoor, *et al.* (1958) report that a high proportion of extra responding occurs immediately after termination of the aversive stimulus. Hence, the present data were separated into those extra responses occurring within the first 20-sec interval of the shock-off period and those emitted during the remaining 100 sec. These data are presented in Table 2. It is evident that a large proportion of the extras are emitted during the first 20 sec. Inspection of the cumulative records and casual observation indicate that a large majority of the extras recorded during the first 20-sec interval are a "spill-over" of the rapid escape run initiated during shock. A decreasing function is evident for the extra rate during the last 100 sec of the shock-off interval and FR length. While the absolute number of responses is small, application of the Friedman two-way analysis of variance by ranks (Siegel, 1956, p. 166F.) yields a probability of

less than 5% of obtaining these ranks by chance. The redetermination data in Table 2 indicate that the trend is not due to the ratios having been run in temporal sequence. Kaplan's (1956) data show a similarly decreasing extra rate as the FR increases.

Experiment II

Behavior during shock. The mean latency of the first escape response in log seconds is plotted in Fig. 4 as a function of shock intensity, also plotted on a log scale. Data for the

Fig. 4. The mean latency of the first escape response over eight sessions as a function of shock intensity for three subjects.

Table 2

Mean Extras per Trial for the Last Five Sessions of Experiment I at Each Ratio for R15 and R7, and for Two Sessions at Each Ratio for R4.

Redetermination data are given separately.

	<i>1st 20 sec</i>			<i>last 100 sec</i>		
	<i>R15</i>	<i>R7</i>	<i>R4</i>	<i>R15</i>	<i>R7</i>	<i>R4</i>
FR 1	0.70	2.57	0.52	0.76	7.90	0.04
FR 5	1.12	0.89	2.37	0.33	0.14	0.02
FR 10	2.10	0.56	2.66	0.28	0.15	0.00
FR 20	1.14	1.20	1.54	0.14	0.06	0.00

<i>Redetermination</i>						
	<i>1st 20 sec</i>			<i>last 100 sec</i>		
	<i>R15</i>	<i>R7</i>	<i>R4</i>	<i>R15</i>	<i>R7</i>	<i>R4</i>
FR 1	1.61	0.64	1.26	0.16	0.53	0.18
FR 5	1.66	0.34	1.50	0.03	0.03	0.00
FR 10	—	0.59	1.44	—	0.05	0.00
FR 20	—	—	2.03	—	—	0.00

control intensity of zero milliamperes yielded few responses and these were of values too high for representation. At intensities of 0.5 ma and below, latencies are high and individual differences are marked. At intensities of 1.0 ma and above, the functions break rather sharply at a value of about 1 sec and the variability between subjects is diminished. These data are in good agreement with the data of Kimble (1955) obtained in a classical avoidance situation, and the findings of Boren, Sidman, and Herrnstein (1959) in a combination escape and avoidance situation in showing the major differential effects of shock on latency to occur below 1.0 ma. At intensities of 1.0 ma and above, these studies show effects similar to the ones observed here.

In Fig. 5, the mean escape rate (the rate prevailing between responses one and five in the ratio run) in responses per second is plotted for each subject as a function of shock intensity. In general, escape rate increases as a function of intensity, but R7 and R4 show a reversal in rate at high intensities, R7 reaching a maximum at 1.0 ma and R4 at 2.0 ma. R15 differs in showing a steadily increasing rate at the higher intensities. The latency function for R15, as seen in Fig. 4, did not flatten at 1.0 ma as did the functions for the other two subjects.

Behavior during shock-off periods. Behavior during the shock-off periods was analyzed as in Exp I. At all shock intensities, less than 2% of the total shock-off time was spent holding the bar down and no relationship between holding and intensity was evident. The data on extras, separated into those occurring during the first 20 sec and those falling during the last 100 sec of the shock-off interval, are shown in Table 3. Again, most of the total extras were observed to occur as part of response runs initiated during a shock-on period. A regular function obtains for those

Fig. 5. The mean escape rate for eight sessions as a function of shock intensity for three subjects.

extras emitted during the last 100 sec of the shock-off period, but in this case, only for two of three subjects. For R7 and R4 the extra rate for the last 100 sec is an inverse function of shock intensity.

DISCUSSION

The results of these two experiments support the consensus evident in the literature that the pause before the initiation of a ratio run and the rate during the run should be regarded as separate dependent variables in the study of behavior maintained by FR schedules. For example, Azrin (1959) found that punishing pigeons responding for food on an FR schedule increased the duration of the pause, but did not reduce the rate of response after the first response had occurred. Similarly, Sidman and Stebbins (1954) found that satiation of rats maintained on FR schedules produced extremely long post-reinforcement pauses, but did not affect the local rate. More

Table 3
Mean Extras per Trial for Eight Sessions of Experiment II

	1st 20 sec			last 100 sec		
	R15	R7	R4	R15	R7	R4
4.0 ma	2.07	0.41	1.82	0.15	0.00	0.00
2.0 ma	1.55	0.50	2.32	0.21	0.00	0.10
1.0 ma	1.50	0.26	1.39	0.19	0.10	0.13
0.5 ma	1.14	0.42	1.46	0.28	0.16	0.68
0.25 ma	1.19	1.41	1.48	0.06	0.76	0.75

recently Azrin, Holz, Hake and Ayllon (1963) found that squirrel monkeys allowed to escape from a stimulus associated with intermittent shocks displayed the common pause-run pattern, with pause duration showing much greater sensitivity than running rate to manipulations of shock frequency and escape duration.

The results of the present study and of Kaplan (1956), showing that as the FR is increased a rat will endure aversive stimuli for increasingly longer periods before the escape process is initiated, bear testimony to the power of the contingencies peculiar to FR schedules. In discussing similar correlations between FR pausing and ratio length in the positive reinforcement case, Boren (1953) and Skinner (1938) offer basically similar interpretations. They point out that reinforcement occurs after a high rate of response and a fixed number of responses have been emitted. When the animal is in a pause, we would expect, through stimulus generalization, the probability of response to depend upon how closely the stimulus conditions of the pause resemble the conditions prevailing at reinforcement. Assuming that each response produces a certain amount of stimulation, which builds up with successive similar responses, at the onset of shock with shorter ratios the organism is closer to its state of response-produced-stimulation at reinforcement than it is at higher ratios, hence the longer pause at higher ratios. In addition, the FR schedule shares certain temporal properties with FI schedules in that the probability of reinforcement at the beginning of the interval is zero. Obviously, the longer the ratio, the greater the interval which must separate shock onset from termination. In fact, Cumming and Schoenfeld (1958) have reported ratio-like pause and run behavior from pigeons exposed to FI schedules for long periods.

The data on escape rate do not fit as neatly into the literature on positive reinforcement as do the data on latency. In Exp I, increasing FR length did not yield a negatively accelerated rate function as in Boren's (1953) study. The present data (Fig. 2) were tentatively described as reflecting "strain" at higher ratios which interfered with the essential constancy of the escape rate. Kaplan's (1957) data on escape rate as a function of FR length, in the author's words, "though suggesting an increase

in rate as a function of ratio size, are equivocal. Their irregular features may be due in part to long periods of non-pedal-pressing, which occasionally intervene after fixed-ratio responding has begun" (p. 156). The relationship between escape rate and FR length thus remains uncertain. In Exp II, escape rate on FR 5 varied greatly with changes in shock intensity (Fig. 5). In the studies cited above (Azrin, 1959; Sidman and Stebbins, 1954; Azrin *et. al.*, 1963) FR rate after the first response has been repeatedly shown to be relatively insensitive to many variables. Boren's finding that it increased with ratio length is an exception to this rule. Of course, comparison of the present data with data from studies on positive reinforcement requires specification of a variable of comparable status with shock intensity. If one's theoretical predilections dispose him toward choosing drive level, then the data of Sidman and Stebbins present a problem, since they found no changes in FR rate after the first response with changes in drive level. If, on the other hand, one stresses the cueing function of electric shock, the functions shown in Fig. 4 and 5 may be considered as either generalization or psychophysical data. Within the escape literature, a curvilinear relationship between the intensity of the aversive stimulus and the rate of escape behavior, passing through a maximum at an intermediate value of the stimulus, has previously been reported by Barry and Harrison (1957) using sound as the aversive stimulus, and by Keller (1941) and Kaplan (1952) using light as the aversive stimulus, all in studies involving interval schedules of reinforcement. Two of three subjects in the present experiment display such a maximum in rate but none shows a minimum in latency of the first response at an intermediate intensity.

On the general problem of maintaining FR behavior during shock, the present results are at variance with those reported by Weiss and Laties (1959) and by Hendry and Hendry (1963). Weiss and Laties report difficulty in obtaining typical FR effects in an escape-from-shock study employing a titrating procedure. Their results in general seem similar to data from Exp II at 0.25 ma, where the rates were low, and may be attributable to small amounts of reinforcement, since reinforcement consisted in a decrease to some other shock intensity rather than termination of shock.

Hendry and Hendry report irregular responding on FR 4 and FR 8 in rats escaping from shock. There are several differences between their procedure and the present one which might account for the discrepant findings. One difference is that Hendry and Hendry delivered shock more directly by means of electrodes implanted subcutaneously. Although their shock level, estimated by the present investigator at approximately 0.75 ma, is quite close to the 0.8 ma used for two rats in the present Exp I, conceivably the subcutaneous method of delivery is more disruptive at higher FRs. While Hendry and Hendry were able to maintain behavior in other animals on a concurrent FR 8 schedule for food and escape reinforcement, and so argued against any necessary disruptive effect of the shock, in this portion of the investigation they raised the shock level gradually. Also, Hendry and Hendry evidently raised the schedule requirement from FR 4 to FR 8 after only two sessions of irregular performance on FR 4, a procedure likely to accentuate behavioral irregularities. However, it must be pointed out that it was necessary to double the shock level for one of the animals used in the present study, R4, in order to maintain responding. Also, some disruption of behavior was noted during the first few sessions at ratios higher than FR 1.

Among the superstitions acquired by the experimenter during the course of this research are the importance of shaving the bodies of the subjects when grid shock is employed and of staying at FR 1 for 16 sessions before raising the ratio. Conceivably, the prior experience of these subjects with bar-pressing for food influenced their behavior under shock conditions. It seems clear that while it is possible to maintain behavior in the presence of shock (see Dinsmoor and Winograd, 1958; Dinsmoor and Clayton, 1963), it remains a somewhat delicate procedure.

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