TITRATION BEHAVIOR ON VARIOUS FRACTIONAL ESCAPE PROGRAMS¹

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An adequate account of how aversive stimuli control behavior must state the relationship between the properties of such stimuli and their behavioral effects. Psychologists have shown most interest in the type of aversively controlled behavior generated by avoidance programs. In many ways, these programs undoubtedly correspond closely to certain kinds of conditions that are met outside the laboratory. But, as Dinsmoor and Hughes (1956) pointed out, avoidance behavior, when used as a model with which to study aversive control, also possesses certain disadvantages. The most prominent is that in accounting for it, one must often appeal to covert events that are at best only indirectly under the experimenter's control.

Escape behavior is simpler in certain respects, despite its lesser capacity to evoke hypotheses about complex human behavior. The parameters of the aversive stimulus can be specified more precisely, can be varied by the experimenter, and can be related to the behavior of the subject by a much shorter chain of inferences than can avoidance behavior.

One property of aversive control about which little is known is how behavior under such control is affected by fractional changes in the intensity of the aversive stimulus. In discussing this question, one investigator (Campbell, 1954) underscored the differences between how we study positive and negative reinforcement. In the typical positive-reinforcement experiment, the strength of the drive—usually based on food deprivation—is not reduced to a minimal value all at once, but only by small steps. Conversely, in the typical experiment in which an aversive stimulus is used to generate behavior, the subject totally eliminates the stimulus if he makes the proper response.

In an earlier paper, we reported that rats would press a lever in order to produce small decrements in the intensity of an electric shock which periodically increased in intensity (Weiss & Laties, 1958). Such a "titration schedule" is similar to the audiometric technique originated by Békésy (1947) and used by Blough (1958) for studying vision and by Lindsay (1957) for studying sleep. It possesses some useful properties for studying escape behavior. It can be arranged to produce much higher frequencies of responding than customary escape programs, can be used with intermittent reinforcement, and can be manipulated parametrically in various ways.

The current paper reports on how certain aspects of titration behavior are affected by variations in the interval between increments in shock level and by variations in the number of responses required to produce a decrement in shock level. Both types of variation are ways of manipulating the response rate necessary to keep the intensity of the shock at a stable value.

METHOD

Apparatus

The shock stimulus was provided by a constant-current stimulator whose output could be increased or decreased in discrete steps. The 25 nearly equal steps between the minimum and

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maximum values of the stimulator current were selected by a two-way stepping relay which was appropriately incorporated into the circuitry. The values of the minimum and maximum intensities of the stimulating current were 0.07 and 0.65 milliamperes, respectively (average value of the wave). The shock current was delivered through a scrambler to a floor of stainless-steel rods in the experimental chamber², which was located in an adjoining room. The walls of the chamber and the two levers in it were included in the shock circuit. The levers, 2 inches long and 0.5 inch in diameter, operated microswitches when depressed with a force of 16 grams or more. Both were connected in the circuit.³ Recordings were made of stimulator output, responses, and the amount of time that was spent on each of the 25 shock steps.

Pulses from a timer connected to the two-way stepping relay periodically raised the output of the stimulator. The output of the stimulator was lowered by pulses which moved the stepping contact in the opposite direction. On some programs, each response lowered the output by one step; on others, a fixed number of responses was required to produce a decrement of one step. A brief tone sounded in the chamber each time a response produced a decrement in shock level.

Subjects

All subjects used in these experiments were adult male albino rats from Wistar and Holtzman stock.

EXPERIMENT I

Procedure

After 6 hours of training⁴ on a titration schedule with an i-i (increment-increment) interval of 10 seconds, each of six animals was run for a 90-minute training period on each of four different i-i intervals: 2, 5, 10, and 20 seconds. Each subject completed all of these intervals on a single day. The sequence of i-i intervals was randomly selected for each animal. After all the subjects had completed this training, they were run for a second time, again with a randomly determined sequence of the four i-i intervals. The data reported here are based on this second session. Only the last 60 minutes of each 90-minute session were used to obtain the distribution of time spent at each shock level.

Results

Figure 1 shows the proportion of time spent by the individual rats at each shock level—each of the 25 steps from the minimum to the maximum output of the stimulator. Figure 2 shows the distribution for all *Ss* combined. For the two higher intervals (i-i = 10 seconds and i-i = 20 seconds) the shock intensity was held at or near the minimum value most of the time. At i-i = 5 seconds, and especially at i-i = 2 seconds, the distribution shifted markedly toward the higher shock levels and also displayed more variability. Medians—that is, the point below which shock level was kept 50% of the time—were computed for

²The chamber was of the type manufactured by Foringer & Co., Rockville, Md.

³Both of the available levers were used in order to reduce the amount of competing behavior (e.g., attempts to escape from the chamber) that occurs in this situation.

⁴Three of the rats used on this study were given 9 hours of training on an avoidance schedule before being placed in the titration situation. The other three rats received no such prior training. The only difference in the behavior of the two groups that we could observe was a longer latency to steady behavior for the rats given no prior training. The rats that had received prior avoidance training maintained the shock at a fairly steady level almost from the beginning. The rats without such training tended to oscillate for a few hours before stabilizing.

Figure 1. Proportion of time spent by the individual rats at each of the 25 steps from the minimum to the maximum shock intensity for all four of the *i-i* (increment-increment) intervals used. The minimum intensity (step 1) was 0.07 milliampere, while the maximum intensity (step 25) was 0.65 milliampere (average value of the wave).

each of these *i-i* intervals by taking step 1 of the 25 steps between the minimum and maximum shock level to extend from 1.00 to 1.99, step 2 from 2.00 to 2.99, etc. These medians are shown in Fig. 3. They reveal not only a progressive shift as a function of *i-i* interval, but also a clear increase in variability among *Ss* with shortening of this interval.

Figures 4 and 5 are records from a recording voltmeter so connected that it traced out an index of stimulator current. As Fig. 3 indicates, the two *Ss* whose records are shown are fairly typical in their performances at the different *i-i* intervals. As one would infer from Fig. 1 and 2, the variability is greater (there is more oscillation) at *i-i* = 2 seconds and *i-i* = 5 seconds than at *i-i* = 10 seconds and *i-i* = 20 seconds.

EXPERIMENT II

Procedure

With the arrangement used in Experiment I, the *i-i* interval governs the rate of responding necessary to compensate for the programmed rise in shock intensity. The rate of responding needed to offset this rise can also be varied by varying the number of times that the lever must be pressed in order to decrease the stimulator output by one step. That is, decrements can be programmed on a ratio schedule.

In Experiment II, performance on *i-i* = 2 seconds and *i-i* = 5 seconds, with each response producing a decrement, was compared with the performance on *i-i* = 20 seconds with either

a fixed ratio of 10 responses (FR 10) or 4 responses (FR 4) needed to produce a decrement in shock level. The situation in which $i-i = 2$ seconds and each response produces a decrement (FR 1) is equivalent to that in which $i-i = 20$ seconds with the FR 10 contingency in that on the average at least one response must be made every 2 seconds to compensate for the programmed rise in shock current. The two situations differ in that with $i-i = 20$ seconds, FR 10 the shock level takes 10 times longer to rise to a particular value than with $i-i = 2$ seconds, FR 1. Once this value is reached, however, the subject must respond at a rate much greater than once every 2 seconds and for a sustained period of time in order to produce a relatively rapid and appreciable decline in stimulating current. An analogous relationship connects the $i-i = 20$ seconds, FR 4 and $i-i = 5$ seconds, FR 1 situations, although the difference is less marked.

Four rats were used in Experiment II. Three of these had been used in the first experiment, and the other, S8, had received equivalent experience. Before the data-collection

Figure 2. Proportion of time spent at each of the 25 steps from the minimum to the maximum shock intensity for all six rats combined on each of the four $i-i$ intervals used.

Figure 3. Median shock levels for each of the four *i-i* intervals noted. The medians are the points below which the shock was kept 50% of the session. The minimum shock corresponds to step 1.

sessions began, all four experimental animals received 2 hours of training on *i-i* = 20 seconds, FR 10, and all reached a stable level of performance within this time.

All animals were run once under each condition in a counterbalanced design, with the restriction that on a single experimental day an animal performed on both *i-i* = 2 seconds, FR 1 and *i-i* = 20 seconds, FR 10, or on both *i-i* = 5 seconds, FR 1 and *i-i* = 20 seconds, FR 4. Sessions lasted 100 minutes; and the amount of time spent at each shock level was recorded during the last 90 minutes.

Results

Figures 6 and 7 compare the time spent at each shock level on *i-i* = 2 seconds, FR 1 and *i-i* = 5 seconds, FR 1 with their respective *i-i* = 20-second analogues (FR 10 and FR 4). The grouped data are shown in Fig. 8. As in Experiment I, the shorter *i-i* interval (*i-i* = 2 seconds) produced a distribution shifted toward the higher shock levels as compared with the distribution obtained with *i-i* = 5 seconds. (Compare the broken lines in Fig. 8.) The effect of the ratio contingency was to shift both of the analogous distributions toward the higher shock levels. Perhaps this result can be grasped more distinctly in Fig. 9, which shows the median shock level for each condition, calculated as in Experiment I. Note that the shifts produced by the ratio contingency are consistent, and that they are much greater with FR 10 than with FR 4.

Figures 10 and 11 indicate that the FR contingency produces a more stable tracing than that obtained under the other conditions, especially when FR 10, *i-i* = 20 seconds is compared with FR 1, *i-i* = 2 seconds. The reason is that the recorded variability has been

Figure 4. Tracings of stimulator output for Rat S4 on the 1-1 intervals noted. Programmed rises in shock intensity carry the recording pen upwards; responses by the rat carry it downwards. The lower border on each chart corresponds to the minimum shock intensity; the upper border corresponds to the maximum shock intensity.

Figure 5. Tracings of stimulator: output for Rat S7 on the i-i intervals noted. (See also Fig. 4.)

attenuated by a factor of 10 for FR 10 and by a factor of 4 for FR 4.⁵ The cumulative records in Fig. 12 and 13 show that the increased stability of the tracing is built into the system mechanically. Those in Fig. 13 were obtained on a recorder running at twice the paper speed of the one used in Fig. 12 so that the shock decrements could be recorded. Note, especially in the upper portion of Fig. 12, how much more steady the behavior is at FR 1, $i-i = 2$ seconds than at FR 10, $i-i = 20$ seconds.

Figure 6. Proportion of time spent by individual rats at each of the 25 steps from the minimum to the maximum shock intensity, showing the comparisons noted.

As we said earlier, the longer $i-i$ interval used with the ratio contingency means that the shock level rises slowly; however, in order to decrease it by several steps when it becomes sufficiently aversive, the rat must respond at relatively high rates. Especially for the $i-i = 20$ seconds, FR 10 condition, the records in Fig. 12 and 13, which are typical, show that the rats tended to behave in accordance with this pattern rather than with the more avoidance-like one of responding at a steady rate. The intermittent nature of this performance appears very clearly in these records.

⁵That is, the shock level rises 10 times more slowly on $i-i = 20$ seconds than on $i-i = 2$ seconds, while 10 responses, rather than 1 response, are required to produce one decrement. Since only increments and decrements appear in the voltmeter tracing, the latter is much more stable than the underlying behavior responsible for it.

Figure 7. Proportion of time spent by individual rats at each of the 25 steps from the minimum to the maximum shock intensity, showing the comparisons noted.

Furthermore, Fig. 13 shows that there are no consistent pauses after the ratio has been run off, nor do the responses seem to be emitted at a constant rate when they do occur. Since both of these features are characteristic of ratio schedules when food reinforcement is used, another experiment was undertaken with higher ratios than those used here. We thought that, as with food, such characteristics of ratio schedules might not appear with small ratios (Ferster & Skinner, 1957).

EXPERIMENT III

Procedure

This section consists of three shorter studies. In the first, the four rats that took part in Experiment II were used. Because all of these were able to maintain a stable shock level at $i-i = 1$ second, FR 1, and because FR 30 with food reinforcement shows definite ratio-behavior features (Ferster & Skinner, 1957), we compared $i-i = 1$ second, FR 1 with $i-i = 30$ seconds, FR 30.

In the second study, the same four animals were used on $i-i = 150$ seconds, FR 50. In the third study, the three animals that were successful in the second study were used on $i-i = 300$ seconds, FR 99.

Figure 8. Grouped data for all four rats showing proportion of time spent at each of the 25 steps from the minimum to the maximum shock intensity on the schedule values noted.

In all three studies, each bar press produced a brief flash of light from two bulbs in the chamber, one above each bar. A tone sounded each time the ratio was completed and the shock lowered by a step.

Results

In the first part of Experiment III, each animal was run for 30 minutes on $i-i = 1$ second, FR 1 followed by 30 minutes on $i-i = 20$ seconds, FR 30. Figure 14 contains the cumula-

Figure 9. Median shock levels for the four conditions noted, calculated as stated in the text.

Figure 10. Tracings of stimulator output for Rat S8 on the conditions noted. The very rapid oscillations in portions of the i-i 20 seconds, FR 10 record are due to instability in the recorder.

tive-response records for two of the rats on $i-i = 30$ seconds, FR 30 and on $i-i = 1$ second, FR 1. Figure 15 contains the corresponding voltmeter records. Two of the four rats were able to maintain a stable shock level on FR 30, while two drifted toward the maximum shock value. (The latter two *Ss* were switched back to $i-i = 1$ second, FR 1 for 30 minutes in order to see whether they had become physically unable to respond. Both were able to cope with the situation as before.) One rat from each of these two categories is shown in the figures. As the experimental period progressed, the rat labelled S1 in Fig. 14 responded at a lower and lower rate, giving, in essence, an extinction curve. Rat S7 maintained an over-all rate about the same as that it emitted on $i-i = 1$ second, FR 1. Even with Rat S7, however, the level at which the shock was kept under the ratio contingency was higher than that under the continuous-reinforcement condition. This result is similar to that in Experiment II. One can also see that the usual characteristics of ratio performance are missing, even with this great a ratio.

Figure 11. Tracings of stimulator output for Rat S1 on the conditions noted. The very rapid oscillations in portions of the $i-i$ 20 seconds, FR 10 record are due to instability in the recorder.

In the second part of Experiment III, each rat was run for 6 hours with $i-i = 150$ seconds, FR 50. Three of the rats maintained a stable level of shock, while one allowed it to drift to the maximum value, and stopped responding. Figure 16 gives the cumulative record for an entire session for one rat, and Fig. 17, the voltmeter recording.

Observe how irregularly this rat—whose performance is typical of the three that performed without extinguishing—responds in this situation, giving no indication that a ratio schedule is in effect. Generally, there does not seem to be any consistent correlation between the occurrence of reinforcements (decrements) and response rate.

In the third part of Experiment III, each rat was run for 3 hours on $i-i = 300$ seconds, FR 99. Only one rat maintained a stable shock level with these values. Figures 18 and 19 show its performance.

Figure 12. Cumulative records for Rat S1 under the conditions noted.

Irregularities in responding are much more prominent here than in the same *S*'s performance at FR 50. The record is marked by long pauses and great fluctuations in response rate when periods of responding do occur.

The other two animals fell behind more and more as the session progressed, eventually ceasing to respond altogether. As with other rats which extinguish on such a program, they tended to huddle, their snouts facing the corner of the chamber. Occasionally, they sprawled on the bars comprising the floor, a posture which has the result of reducing current density in the tissues.

Figure 13. Cumulative records for Rats S8 and S7 on the conditions noted. The slash marks on the record indicate the occurrence of decrements.

DISCUSSION

Rats continue to press a lever when doing so leads to small decrements in the intensity of a shock stimulus. The level below which the shock is kept half the time (also the point at which the probability of a response is high enough to match the programmed rises in intensity) is a function of the rate of rise: the more rapid the rise, the higher this level. If a ratio contingency is interposed, so that several responses have to be made to produce a

Figure 14. Cumulative records for Rats S1 and S7 on the conditions noted. The slash marks indicate the occurrence of decrements.

fall of one step in shock level, the median shock level is higher than the continuous-reinforcement condition, which requires the same over-all frequency of responding in order to maintain a stable shock level.

Figure 15. Tracings of stimulator output for Rats S1 and S7 on the conditions noted. Observe that Rat S1 extinguished while Rat S7 continued to respond.

What features of titration schedules as we have used them account for these phenomena? Consider first the increase in median shock level which accompanies a shortening of the i-i interval. The hypothesis that immediately suggests itself is that keeping up with the programmed rate of rise in shock level becomes physically harder and harder as the i-i interval grows shorter—that the rat is quickly approaching an upper limit of response rate. One objection to this hypothesis is the implication that the shock level should drift upwards as the experimental session goes on. The records show plainly that this is not the case. Another objection is that in many instances rates of responding are sustained which far exceed the greatest rate of rise in shock level that was used.

Figure 16. Cumulative record for Rat S8 on the condition noted. The slash marks on the record indicate the occurrence of decrements in shock level. The slash marks on the horizontal lines below each portion of the record indicate the occurrence of increments in shock level. The session lasted 6 hours.

A more likely explanation might be that the rat engages in behavior which competes with lever pressing. Such competing behavior might consist of attempts to escape from the chamber, attempts to minimize the effects of the shock by assuming various postures, and so on. This leads to a response lag which has a much greater effect when the shock is rising rapidly than when it is rising slowly. That is, as in a physical system, a constant phase lag results in a greater integrated error with a high frequency than a low one. By a simple extension of this analysis, we can also account for the further rise in shock level introduced by the ratio contingency. In this case the lag periods can be seen clearly on the cumulative records. If the rat did not lag, we should find no difference in median shock level as a function of i-i interval until the physical capabilities of the animal were exceeded.

The account above points up the formal relationships. But the properties of the behavior itself call for a more thorough analysis. One obvious property is that the particular drive state is being manipulated very directly. And, as is usual with other kinds of drives, the more intense the drive state the greater the probability of a response. But the probability of a response is not merely a function of the shock level. It also depends on the immediately prior conditions. Observe, for example, the $i-i = 2$ -second records in Fig. 4 and 5. These show definite wave-like properties. The shock intensity generally rises until it evokes a series of responses which carries the shock level to a point which generally fails to evoke responding when approached from the other direction.

Figure 17. Tracings of stimulator output for Rat S8 on the condition noted. Each segment of the record represents 2 hours of the total 6-hour session.

Such behavior is associated with psychophysical threshold measurements of various modalities in both humans and lower animals. In the present case, the surface similarities only partly reflect the actual ones. The tendency for series of responses to be emitted follows from the nature of the situation. Since, when each response produces a decrement in shock level, a train of responses produces a greater fall in shock level than a single response, such trains become differentially reinforced and thus more likely. They therefore differ from the "bursts" observed with avoidance schedules (Sidman, 1954) in that they are not due to factors such as adventitious reinforcement.

Figure 18. Cumulative record for Rat S8 on the condition noted. The slash marks on the record indicate the occurrence of decrements in shock level. The slash marks on the horizontal lines below each portion of the record indicate the occurrence of increments in shock level. The session lasted 3 hours.

One reason for wave-like records not appearing at the longer *i-i* intervals is that a shock-intensity range was used which evoked enough responding even at the minimum shock value to offset the programmed rises in shock level. In an earlier study (Weiss & Laties, 1958), we observed oscillations in shock level even at *i-i* = 20 seconds when we used a range of shock values with a lower minimum intensity and less steep rate of rise than that used in the current experiments. Figure 20 shows some records from that study.

The foregoing comments on the causes of oscillations observed in the tracings apply also to the ratio situation, although, in the latter, a sustained series of responses leads to a smaller decrement in shock level. Performance on the ratio programs also exhibits some unique features of its own. The most striking is the lack of regularity or patterning (in relation to the occurrence of reinforcements) in the cumulative records within a wide range of ratios. With food reinforcements, behavior of this sort may appear on very high ratios or when the reinforcement is small (Ferster & Skinner, 1957). But with food reinforcement it is a prologue to extinction. Because behavior is maintained for long periods of time in the present case and the shock level is therefore kept at a fairly stable value, another explanation for the irregularity must be advanced. One possibility is that it arises from the in-

Figure 19. Tracings of stimulator output for Rat S8 on the condition noted. Each segment represents 1 hour of the total 3-hour session.

distinctiveness of the reinforcement, because the reinforcement is an event that neither requires a consummatory response nor brings about a clearly marked change in the environment. The indistinctiveness is exaggerated by transients introduced by the scrambler and by the fact that shifts in the rat's posture which increase or decrease the area of body surface in contact with the grid also produce changes in current density in the tissues.

One source of support for the indistinctiveness hypothesis comes from those figures on which increments in shock level are indicated by slash marks on the horizontal line below the record. (See Fig. 16 and 18.) No consistent correlation can be observed between responding and the occurrence of increments. A more precise notion of this lack of correlation

Figure 20. Tracings of stimulator output for five rats on $i-i = 20$ seconds, FR 1 with a lower shock range than that used in the current experiments. The insets to the left of each record show the programmed rate of increase in shock level.

was given in our earlier study (Weiss & Laties, 1958), in which we recorded the distribution in time of the responses made between increments in shock level. We obtained what was essentially a rectangular distribution, and concluded that no correlation was present.

If a fall in shock level of only one step is *not* discriminated by the rat, then there is no essential difference between the situation in which each response produces a decrement and that in which several responses are required. In both instances the rat is on a ratio schedule anyway, since only sustained series of responses are followed by distinguishable changes in shock intensity. Because these changes are gradual rather than abrupt, titration behavior might have some interesting counterparts outside of the laboratory. On many occasions, especially with behavior under aversive control, there is no clear-cut reinforcement to maintain behavior. For instance, that textbook favorite, the obsessive-compulsive hand washer, may continue to perform this response just to keep an emotional state from exceeding a certain aversive intensity which it tends to approach. This state does not disappear—it is just being kept under control.

SUMMARY

Rats were trained to press a lever to reduce the intensity of an electric shock. The intensity of the shock was periodically raised. For the range of intervals between increments used in the current experiments, the shorter the interval the greater the amount of shock taken by the rat. Reductions in shock level could also be programmed on ratio schedules. The effects of fixed ratios ranging from 4 to 99 on this kind of behavior are described.

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