TIMING IN FREE-OPERANT AND DISCRETE-TRIAL AVOIDANCE¹

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A procedure ("discrete-trial" avoidance) was devised to differentiate between the two main theories of responding in Sidman's "free-operant" avoidance procedure. One theory, a version of two-factor theory, holds that responding is reinforced by the removal of a conditioned aversive stimulus. The conditioned aversive stimulus is held to be temporal, which accounts for the spaced responding, or timing, that Sidman's procedure produces. The other theory holds that the reinforcement for both responding and timing is shock-frequency reduction. The new procedure eliminated this reinforcement for timing, but retained the conditions for the formation of conditioned aversive temporal stimuli. According to one theory, the new procedure should have sustained timing as well as Sidman's, while according to the other, it should have sustained no timing. The results confirmed neither theory. Timing was found with both procedures, but unequally in degree and kind. Large variations in the precision of timing did not appear to be correlated with successful avoidance for either procedure.

What is the reinforcer for avoidance responding? Is it the postponement or omission of a remote aversive event, or must it be some immediate consequence? The tradition of avoidance theories clearly favors something immediate. Traditional theories of avoidance were conceived to explain responding on procedures that provide an immediate stimulus change after each response. Each response avoids shock at the same time that it terminates an arbitrary stimulus (*e.g.*, a tone) that comes on a few seconds before the shock is due. The traditional theory posits two processes or factors: the tone becomes "fearsome" or "aversive" by virtue of its temporal proximity to the shock; removal of the tone strengthens the response, which only incidentally avoids the shock (Mowrer, 1947).

Sidman's avoidance procedure (1953) challenged two-factor theory by omitting any external conditioned stimulus to mediate responding. On this procedure, brief inescapable electric shocks are delivered periodically (as determined by the "shock-shock", or SS, interval) to the walls and floor of a cage containing an animal, typically a rat, and a response lever. A depression of the lever interrupts the

sequence of shocks by delaying the next one for a fixed amount of time (the "response-shock", or RS, interval). If the animal responds so rapidly that its longest interresponse time never exceeds the RS interval, it will receive no shocks. But if it should pause until shocked, then the train of shocks will resume according to the SS interval, until the next response. Avoidance responses here do not change the animal's immediate surroundings; they merely postpone the next shock.

By postulating a hypothetical class of stimuli, Anger (1963) adapted two-factor theory to account for responding on Sidman's procedure. He noted first that animals can respond to the passage of time in many types of situations, including conditioning with schedules of positive reinforcement and Pavlovian delay and trace conditioning. He then pointed out that in Sidman's procedure, shocks are correlated with fixed times since discriminable events—responses and previous shocks—and that these times, however they are sensed by the animal, may replace the arbitrary warning stimuli of conventional avoidance procedures. To substantiate this notion, Anger called on the fact that animals in Sidman's procedure tend to "space" their responses, which is to say that response probability increases with time since the previous response, instead of remaining constant as it would if responding were random. When an animal spaces its

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responses, it is, with each response, removing a relatively long post-response time and replacing it with a short post-response time. Long post-response times should, according to theory, be more aversive than short ones because they approximate the RS interval and therefore resemble the interval paired with shock. Anger thus purported to explain not only why animals respond at all, but also why they respond nonrandomly in time.

Unlike Anger and others (*e.g.*, Mowrer, 1960), Sidman (1962, 1966) has suggested that responding in his procedure may not require an immediate consequence to maintain it. Instead, he proposed that the reinforcer is the actual reduction in the frequency of shock, and that the postulation of mediating conditioned aversive stimuli is superfluous. The spacing of responses, he explained by invoking a second consideration: "The animal will gain more time free of shock with two well-spaced responses than by spacing two responses close together . . . the temporal discrimination is a second-order process, with temporally spaced responses emerging through differential reinforcement from a higher, less efficient response rate (Sidman, 1966, p. 466 f)."

Thus, there are two fundamentally different accounts of responding in Sidman's procedure, both as regards the occurrence of responding and its temporal distribution. Moreover, both theories seem to be in full accord with the available evidence at the time of their formulation. In Sidman's original procedure and in related procedures, there is a confounding of the two alternative means of reinforcement. Well-spaced responses gain the greatest shock-free time for a given number of responses, but they also terminate the most aversive temporal stimuli, as inferred from the pairings between specific time intervals and shock. To choose between the theories, a procedure is needed in which differential predictions arise, something that previous studies have not provided. The present experiment was an attempt at such a differentiating procedure. Each avoidance response here avoided just one shock, and the time distribution of responses had no effect on either the overall or the local rates of shock. Yet, the procedure still permits the differential pairing of shock with time, as called for in Anger's account of Sidman's procedure. Therefore, according to Anger's theory the new procedure retains the critical features of Sidman's

original procedure, and should produce spaced responding. And according to Sidman's theory, the present procedure should not support spaced responding.

METHOD

Subjects

Ten brown female rats of the Lashley strain were used. Rats B-1, B-2, B-3, B-4, R-5, and R-6 were approximately 100 days old and experimentally naive when introduced into the experiment; B-5 and B-6 were experimentally naive and approximately 200 days old. T-1 and T-2, about a year old, were run on Sidman avoidance in a separate experiment, from which some data were extracted for special treatment here. Subjects designated with the same letter are littermates. All subjects were kept in individual home cages with free access to food and water.

Apparatus

The experimental chamber was a standard rat box with a grid floor made of stainless steel bars 0.25 in. (6.35 mm) in diameter and spaced 1 in. (25.4 mm) apart center-to-center. During the first (Sidman) procedure the response lever was a modified telegraph key that protruded 1.5 in. (38 mm) into the box at a height of 3 in. (76 mm) above the grid floor and required about 20 g (0.196 N) to operate. Unlike levers employing microswitches, its make and break points coincided at the low point of its excursion. A transparent false ceiling sloped up and back from a point 2 in. (51 mm) above the response lever, preventing the animals from perching on the lever. For the second procedure, the false ceiling was removed, and a high-speed retracting response lever was employed which, when retracted, formed a panel flush with the wall of the box (Hineline, 1968). When extended, this response lever protruded 1.25 in. (32 mm) into the box at a height of 3 in. (76 mm) above the grid floor. With both procedures, ac shocks of 0.3-sec duration were delivered to walls, grid, and lever with scrambled polarities at an intensity of approximately 0.8 mA, measured across a precision resistor in series with the common of the scrambler. Conventional switching circuits were used for scheduling and recording. White noise was supplied to the experimental chamber at all times. A door-

bell buzzer was occasionally operated at the lowest voltage permitting reliable operation, as described below.

Procedure

First, B-1, B-2, B-3, and B-4 were subjected to daily 100-min sessions of Sidman avoidance conditioning with $RS = SS = 20$ sec. After 64 sessions the second procedure was introduced and more animals were added.

The next procedure was scheduled in relation to a fixed 20-sec cycle (see Fig. 1). In the absence of responding, a brief shock was delivered at the end of each cycle, and the lever remained in the box continuously. A response retracted the lever immediately and until the end of that cycle; the shock for that trial was omitted, and the lever returned to the chamber to initiate the next cycle. Only one response could occur in each 20-sec cycle, and each response could eliminate only one shock. The latency of the response, whether short or long, therefore had no effect on the amount of shock-frequency reduction. Since the cycles are juxtaposed, this procedure is identical to the Sidman procedure so long as no responses occur. And if responses occur in each cycle, the procedure resembles discriminated avoidance procedures (Hoffman, 1966),

with a fixed 20-sec interval between presentations of the warning stimulus and an intertrial interval equal to the difference between 20 sec and the response latency for each trial. Because it permits no more than one response per cycle and because the cycles are clearly marked off by stimuli, this procedure will be referred to as the "discrete-trial procedure". Sessions lasted 300 cycles, regardless of the number of shocks delivered.

For odd-numbered animals, the buzzer sounded only while the lever was extended; for even-numbered animals, the buzzer sounded only while the lever was retracted.

On both procedures, the houselight was on continuously throughout the session, and each lever press produced an audible click, unless the lever was in the retracted position. Presses on the retracted lever, which was at these times a panel flush with the wall of the chamber, were recorded but had no effect on the procedure.

RESULTS

The two procedures have a key feature in common. Shocks are scheduled to follow a discriminable event by an interval of 20 sec. In the Sidman procedure, the interval is

Fig. 1. Schema for the discrete-trial avoidance procedure. Indicated by the top line of the diagram, time progresses from left to right, as each of the lower three lines describes a sequence of events with a particular sequence of responses. Upward displacements in these lines indicate when the lever is extended; downward displacements indicate when the lever is retracted. An "X" indicates the occurrence of a shock; an "O" indicates the occurrence of a response. The bottom line describes the sequence of events with responses occurring on alternate trials. The next line up shows the sequence of events with a response on each trial, and the third line from the bottom shows the sequence of events with no responses at all.

measured from a shock or a response. In the discrete-trial procedure, it is measured from a shock or from the sudden insertion of the lever into the chamber, combined with onset (or offset) of the buzzer. The comparison of performances on the two procedures will deal with the distributions of responses within the 20-sec interval.

Sidman Procedure

Figure 2 shows conditional probability plots ("interresponse times per opportunity", or IRTs/op) for B-1, B-2, B-3, and B-4 on the Sidman procedure. This measure is obtained from the simple frequency distribution by dividing the number of responses in a given class interval by the number of interresponse times (IRTs) greater than the lower limit of that class interval (see Anger, 1963 or Sidman, 1966). To exclude unreliably small samples, the statistic was not computed when the number of opportunities fell below 20. Deviations from constancy in this statistic indicate time-correlated changes in response probability; randomly spaced responses would produce a horizontal plot. The heavy curves, showing data pooled over Sessions 5, 6, and 7 for each animal, are representative of the conditional probability curves that were plotted weekly throughout the 64 sessions of Sidman avoidance conditioning; they are also similar to plots taken in other laboratories (Anger, 1963). Each curve shows a high conditional probability of responding at short IRTs, followed by a steep drop at intermediate times, and then a rising portion at the longer IRT values. The rising portion of the curve describes an increasing conditional probability of response with time since the preceding response.

There were occasional deviations from this pattern. The thinline plots for Rats B-1 and B-4, each based on a week's data, reveal that there were sessions in which temporal factors were less important than in the sessions contributing to the other, more representative plots. The flat curve at long IRTs for B-1, and the negative slope of the curve for B-4, suggest that reinforcement for these animals was sometimes not critically dependent upon the removal of conditioned aversive temporal stimuli. The absence of timing was not correlated with deterioration of avoidance, for in the sessions contributing to flat IRTs/op curves,

Fig. 2. Conditional probability of response (IRTs/op) as a function of interresponse time for Rats B-1, B-2, B-3, and B-4 during Sidman avoidance conditioning, with response-shock and shock-shock intervals both equal to 20 sec. The heavy-line plots are based on the pooled data of Sessions 5, 6, and 7; the superimposed thinline plots, for B-1 and B-4, are based on pooled data covering the seven-day period with strongest evidence for randomly spaced responses. The statistic was computed for each 2-sec class interval by dividing the number of IRTs within a class interval by the number of IRTs exceeding the lower limit of that class interval. The final class interval (IRTs greater than 20 sec) necessarily has the value of 1.0 and is therefore trivial. The tenth class interval was not plotted whenever the number of opportunities for response fell below an arbitrary criterion of 20.

no animal was taking more than 5% of the possible 300 shocks per session.

Discrete-Trial Procedure

Figure 3 shows performances of B-1, B-4, B-5, B-6, R-5, and R-6 on the discrete-trial procedure. Each graph is based on more than 2000 responses. B-1 and B-4 were retained from the Sidman procedure; the others were trained initially with the new procedure. Statistics computed for this figure are comparable to those computed for Fig. 2, but they are based on time from the insertion of the lever until response, instead of simply the time between responses. A trial with no response counts as an opportunity for response in each of the 2-sec class-intervals. A trial with a response adds opportunities only for intervals preceding or including the response, for in the discrete-trial procedure, responses cannot occur while the lever is retracted. The data plotted as dots in Fig. 3 are taken from the week, for each animal, showing strongest evidence for spaced responding. Each of these graphs shows positive slope, and for five of the six animals the curves indicate temporal discriminations comparable in sharpness to the best ones obtained on the Sidman procedure. There are, however, reliable differences between the distributions for the two procedures. The discrete-trial distributions usually, although by no means always, lack the first mode, corresponding to the so-called "bursts" of responses often found with Sidman's procedure. A first mode for the discrete-trial procedure would indicate an excess of short latency responses, rather than the closely spaced responses that are common with Sidman's procedure. Its absence may simply show the effect of withdrawing the lever immediately after a response. The other major difference may not depend so obviously on the restrictions of either procedure. Unlike the timing in Fig. 2, which is typified by a horizontal region of the curve followed by a sharply rising region, the timing shown in the dot-plots of Fig. 3 formed continuously rising, virtually linear functions. Both of these differences are present for all animals, including B-1 and B-4, which were run on both procedures.

Although there is no doubt that the animals were spacing their responses during the sessions that contributed to the dot curves, the curves plotted with asterisks show that timing

Fig. 3. Conditional probability of response as a function of time since the beginning of a trial for Rats B-1, B-4, B-5, B-6, R-5, and R-6, on the discrete-trial avoidance procedure. The measure, conditional probability of response, is comparable to IRTs/op used with the Sidman procedure. It is obtained for each 2-sec class interval by dividing the number of response latencies therein by the number exceeding the lower limit of the class interval. The data plotted with dots were taken from the week (seven 100-min sessions) showing, for each animal, the best evidence for spaced responding on this procedure. The data plotted with asterisks are taken from the week showing the poorest evidence for spaced responding. As before, the conditional probability is not computed for class intervals in which there were fewer than 20 opportunities.

was not the rule in all sessions. The curves plotted with asterisks are the conditional probability plots for the week for each animal showing the strongest evidence against spaced responding. For five of the six animals the asterisk plots show strongly negative slopes, indicating that for at least one week of performance the probability of response actually dropped as the shock approached. As with the Sidman procedure, timing and avoidance showed little if any correlation, as shown by the percentages of shocks avoided, at the right of each plot in Fig. 3. Comparing the two sets of data in Fig. 3, it may be concluded that the discrete-trial procedure allows greater departures from timing than does the Sidman procedure.

The validity of the differences between the two sets of data in Fig. 3 is supported by Fig. 4, showing conditional probability plots for eight consecutive weeks for B-6 and plotted in chronological order from bottom to top. While both positive and negative slopes are seen, they tend not to be found adjacent to one another, but rather are separated by transitional curves of intermediate slope. Even the irregularities in the curves show some continuity from week to week. At least this animal's behavior was changing slowly from week to week, suggesting that the conflicting results in Fig. 3 are not the result of random variation, but of systematic trends. As before, the changes in spacing of responses accompanied a consistently high level of performance; the rat never avoided less than 99.4% of the shocks during the weeks contributing to Fig. 4.

Inhomogeneity of Responding and Its Measurement

According to Fig. 4, the timing of responses can be reliably unstable, shifting over large blocks of measurements. The timing may also shift quickly, within blocks of measurements such as those pooled in the data shown above. Such changes would demand attention, since conditional probabilities (IRTs/op) are affected peculiarly when computed on an inhomogeneous population—that, over data sampled from more than one distribution. The long-term changes seen above could manifest shifting patterns of short-term change.

The effects of inhomogeneity can be pre-

Fig. 4. Conditional probability of response as a function of time since the beginning of a trial for Rat B-6 on eight consecutive groups of seven sessions on the discrete-trial procedure. The vertical axis has been compressed to conserve space, but the shapes of the curves are the same as they would be if plotted separately, each on its own axes. The vertical scale indicated at the left is valid for all functions shown.

dicted mathematically.² A conditional probability plot with positive slope cannot be obtained unless at least one of the contributing distributions would itself produce a positive slope. Two distributions with constant but different probabilities (*i.e.*, random responding at two different rates) combine to produce a conditional probability plot with negative slope. Two distributions that produce conditional probability plots of negative slope combine to produce a third plot of negative slope. Distributions of differing positive slopes produce more complicated results—two samples with different monotonically increasing functions combine to produce either monotonic or nonmonotonic functions—but these also tend toward negativity. Anger (1963) published some examples of combinations of dissimilar distributions in his discussion of the problem of inhomogeneity. He showed that a combination of two distributions each having positive slope may produce a conditioned probability plot with negative slope. In general, it has been found that inhomogeneous data yield plots more negative than the component distributions. Thus, if some feature of an animal's temporal distribution of responses were to change systematically during a session, the evidence for spaced responding could disappear or diminish in the pooling of the data. For this reason, and also because information on the homogeneity within sessions on the two procedures may be intrinsically interesting, the following section presents data describing rapid changes in the distributions of responses.

The primary data are photographs of an oscilloscope face (Blough, 1963) depicting successive IRTs or response latencies. Location on the horizontal axis of the oscilloscope is determined by a potentiometer driven either by responses or by a clock. Location on the vertical axis depends upon the voltage across a capacitor in parallel with a resistance. It is at zero with the capacitor, C , fully charged and moves upward as the capacitor discharges through the resistance, R . The intensity of the oscilloscope trace is kept below the threshold of the film except occasionally, when it is increased briefly to record the momentary posi-

tion of the trace. Usually, each response flashes the trace and recharges the capacitor. As the capacitor discharges through the resistance, the voltage across the RC circuit decreases as an exponential function of time: $V = V_0 e^{-t/RC}$, where V_0 is the charging voltage, t is the time in seconds after the charging voltage is removed, and e is the base of Napierian logarithms. With this circuit, the rate of capacitor discharge, and therefore the rate of vertical movement of the oscilloscope trace, can easily be regulated by adjusting the resistance, R .

A comparable exponential function is involved in the IRT distribution or latency distribution of a randomly responding animal. Here, the exponential function describes, instead of voltage, the fraction of IRTs (or latencies) that are greater than time t ; the specific expression is $e^{-t \times \text{resp per sec}}$ (Mueller, 1950).

If the time constants of the two exponentials are matched ($RC = \text{sec/responses}$), the resulting pattern of dots will be distributed uniformly over the oscilloscope picture (for example, see Fig. 7 below). Non-random responding is revealed by clustering of the dots.

The exact response rate for a given session cannot be predicted in advance, while the RC circuit is adjusted before the session. Therefore, the two exponentials are unlikely to be in exact agreement, in which case random responding would not be uniformly distributed across the picture, but rather be slightly shifted toward bottom or top. An unchanging, random or nonrandom, distribution of responses throughout a session gives an unchanging vertical distribution of dots across the horizontal axis. Changes in the vertical distribution comprise evidence for inhomogeneity. A stable bimodality or clearly asymmetrical clustering along the vertical scale is evidence for homogeneous nonrandomness of responding.

Inhomogeneity with Sidman's Procedure

Figure 5 shows a 100-min session with Rat T-2; the horizontal axis was controlled by time rather than responses. The dots are distributed bimodally, indicating "bursts" of responding and a temporal discrimination. The corresponding IRTs/op curve (see Fig. 5) confirms the presence of a high density of short IRTs (less than 2 sec), and a cluster of IRTs

²Thanks are due to Mr. Douglas Tang of the Walter Reed Army Institute of Research for the mathematical treatment of IRTs/op.

at some longer duration. No marked inhomogeneity appears in this picture, except for the occasional heavy clustering at very short IRT values.

Figure 6 shows a comparable picture for Rat T-1, but with the x-axis stepped along by responses rather than time. The twelve hundredth through the twenty-one hundredth re-

sponses of a session are represented on the horizontal axis, giving evidence for inhomogeneity that was commonly seen in several animals. Inhomogeneity observed on the Sidman procedure usually took the form of strings of short IRTs interspersed among periods showing a wider range of IRTs. As noted above, inhomogeneity tends to obscure temporal discrimination as measured by IRTs/op. Since the accompanying IRTs/op curve (Fig. 6) indicates temporal discrimination for the session as a whole, it may be concluded that timing with Sidman's procedure is, when present, more precise than has heretofore been supposed on the basis of IRTs/op. At the same time, however, it appears that timing is also more labile.

Fig. 5. Spacing of responses during Sidman avoidance for Rat T-2 during a 100-min session of Sidman avoidance. The upper part of the figure is comparable to those shown previously; it shows conditional probability of response (IRTs/op) as a function of time since the preceding response. The lower portion of the figure is based upon the same session of avoidance conditioning. The horizontal axis represents time during the experimental session. On the vertical axis, time between responses is represented on an exponential scale. Each dot thus represents an interresponse time. The heavy clusters of dots were produced by a number of approximately equal interresponse times occurring at nearly the same time during the experimental session. If responding were random with a median interresponse time of 4.5 sec, the dots would be distributed uniformly over the entire picture. Clustering of dots along the vertical scale indicates spacing of responses; changes in the clustering of dots as one moves along the horizontal scale indicates inhomogeneous performance, that is, shifting distributions of IRTs during the session.

Fig. 6. Spacing of responses for Rat T-1 during a 100-min session of Sidman avoidance conditioning. The upper part of the figure, as in preceding figures, shows IRTs/op as a function of time since the preceding response. The lower portion of the figure is based on the same sample of data, showing successive IRTs for approximately 900 responses emitted during the middle portion of the session. If responses had been randomly distributed with a median IRT of 6 sec, the dots would be unsystematically scattered over the whole figure.

Inhomogeneity with the Discrete-Trial Procedure

Distributions of responses on the discrete-trial procedure omit the time during which the lever was retracted, since during these times there is no opportunity for response. With lever-out time deleted, this procedure is formally analogous to Sidman's procedure for purposes of analysis, with SS interval = 20 sec, RS interval = 20 sec, and the response latencies (time from lever insertion to response) serving as interresponse times.

Figure 7 shows a random-looking, homogeneous distribution of dots (R-6, Session 89). Successive trials are on the abscissa; time from lever-insertion until response is on the ordinate. Given the number of responses and the total time the lever was present, it is possible to calculate an exponential function for the proportion of response latencies greater than t as a function of t (t = seconds since trial onset). At the bottom of Fig. 7, the theoretical curve is shown as the solid line; the empirical results are plotted as the dashed line. The close match indicates an essentially random distribution of latencies; it also corroborates the decision to delete the time periods when the lever was retracted. The IRTs/op curve for latency is also shown in Fig. 7 and further substantiates the randomness of responding in this instance.

Figure 8 shows data for several rats, in sessions chosen for inhomogeneity. Again, successive trials are indicated on the abscissa; response latencies are shown on the ordinate. The most common pattern was that shown in part A of Fig. 8, where there is a steadily increasing upper limit to a dispersed distribution of dots. The shifting upper boundary was sometimes superimposed on other patterns of responding. An example is part B of Fig. 8, where the upper boundary shifts during the first quarter of the session, superimposed on an otherwise stable bimodal distribution of response latencies. In part C, there is a clear lower boundary as well as an upper boundary. During the first half of the session, responses were tightly packed in a well-defined but upwardly shifting mode, until a shock was delivered. In other cases, a similar upward drift was disrupted before a shock occurred. Occasionally there were rapid cyclic changes in successive response latencies during mid-ses-

Fig. 7. Spacing of responses for Rat R-6 during Session 84 of discrete-trial avoidance. The top part of the figure shows conditional probability of response as a function of time since trial onset—analogue to IRTs/op on a Sidman avoidance procedure. The middle portion of the figure shows successive response latencies during the same session: successive trials are indicated on the abscissa; time from the onset of a trial to response is indicated with an exponential scale on the ordinate. Each dot represents one response; no response on a trial simply omits the dot for that trial. The bottom portion of the figure shows the proportion of response latencies greater than t as a function of t , the time since the onset of the trial (from which response latencies are measured). The solid curve is described by the equation, $\gamma = e^{-.154t}$, which is the locus of random responding.

sion. One example is portrayed in part D, which contains one well-defined ascending series of latencies, with hints of two or three others.

Each part of Fig. 8 was chosen for inhomogeneity. In spite of this, conditional probability plots for each of the corresponding sessions, based on data pooled over entire sessions, show positive slopes beyond 4 sec. The marked inhomogeneities failed to obscure the evidence of spaced responding. Consequently, when the evidence for spaced responding was absent, the animals had either indeed stopped timing, as in Fig. 7, or the inhomogeneities must have been far more extensive than those observed in the pictures shown here. There was, however, no instance of a random IRTs/op curve coupled with a picture showing inhomogeneity of spaced responding. In contrast, sessions like Fig. 7 were common, where random responding showed up in both the oscilloscope picture and in the IRTs/op. Thus, it is unlikely that inhomogeneity ex-

plains the random responding occasionally found with IRTs/op computed over sessions.

Extinction of Discrete-Trial Avoidance

A common form of inhomogeneity for the discrete-trial procedure was the upward drift of latencies, particularly, but not exclusively, at the start of a session (see Fig. 8). Since the rats were avoiding successfully, hence receiving few shocks, the rise in latency could have been a manifestation of extinction. Continued responding results in the omission of shocks; omission of shocks, tantamount to extinction, might lead to longer and longer response latencies. Only when a latency becomes long enough, does a shock occur. The shock would then produce "reconditioning" with a consequent reduction in response latency on succeeding trials. To examine the possibility that extinction was the source of the drifting patterns of response latencies, the shock generator was disconnected for B-5, B-6, R-5, and R-6, all on the discrete-trial procedure. The lever

Fig. 8. Dot pictures showing four types of inhomogeneity of performance on the discrete-trial avoidance procedure, along with conditional probability plots based on the same experimental sessions. Parts A and D are for Rat B-5 during the one hundred eighty-seventh and two hundred ninetyeth sessions, respectively. Part B is for Rat B-6 during Session 289; part C is for Rat B-4 during Session 334. The dot pictures show response latencies on exponential ordinate scales, with successive trials represented linearly on the abscissae. The conditional probabilities were computed for each 2-sec class interval by dividing the number of responses within a class interval by the number of times the lower limit of that class interval was reached without an intervening response. The statistic was computed only when this latter, the number of opportunities for response, exceeded 20. Each dot picture characterizes numerous others that were obtained from both the same and from different animals.

position and buzzer remained correlated with responses just as during conditioning.

In order for extinction to account for the drifts in response latencies within the 300-trial, 100-min sessions, responding should extinguish rapidly, on the order of one or two sessions. This did not occur. One rat, R-6, had dropped to low rates of responding by the third session of extinction (*i.e.*, 300 min) with only some 350 responses having been emitted. But the response rate of B-6 was virtually undiminished through some eight sessions and 2000 responses, and the responding of B-5 and R-5 persisted through some 30 to 40 sessions before showing any significant decrement, with the totals containing over 10,000 responses. Thus, for all but R-6, the observed drifting of the response latency distributions during single conditioning sessions could hardly have been produced by simple extinction.³

Not only was responding itself resistant to extinction, but the temporal discrimination was too, as shown in Fig. 9 for B-5. Figure 9A, showing the final session before extinction, has a steep positive slope denoting a temporal discrimination. Sixteen extinction sessions later, after over 4500 responses without a shock, the temporal discrimination still persists, only slightly diminished (Fig. 9B). In the seventeenth session of extinction, the discrimination was wiped out at long latency values (9C) and by the twenty-sixth session (9D) the

³The extinction data require some comments peripheral to the main discussion. R-5 and B-5, whose responses eliminated the buzzer, extinguished far more slowly than did R-6 and B-6, whose responses produced the buzzer. There was a similar, though less striking, difference during acquisition: animals learned more quickly if their responses eliminated the buzzer than if they produced it. The buzzer may therefore have been mildly aversive, independent of its direct association with shock. Its presentation may have constituted mild punishment of the responding of B-6 and R-6, and its removal may have constituted slight negative reinforcement of the responding of B-5 and R-5. That this difference between the effects of the buzzer and that of silence is a genuine difference in primary aversiveness cannot, however, be positively stated, for there is an asymmetry between the two conditions. The experimental counterbalancing of stimuli within the experiment does not take account of the fact that all subjects lived in a non-buzzer environment outside of the experiment. To balance fully for the effects of the buzzer *per se* would have taken at least two more groups of subjects, identical with the two used here in all respects except that the buzzer be present continuously during extra-experimental time.

Fig. 9. Conditional probability of response as a function of time since the beginning of a trial for Rat B-5 during the final session of conditioning with discrete-trial avoidance, and three later sessions of extinction. Each 100-min session included 300 trials. Part A is taken from the final day of conditioning. Parts B, C, and D are taken from Sessions 16, 17, and 26, respectively.

entire probability plot had become horizontal. It is quite possible that periods of spaced responding persisted throughout extinction, however, for one effect of extinction is an increase in protracted periods of non-responding, the kind of inhomogeneity shown to flatten the conditional probability plot.

DISCUSSION

The present experiment was devised to choose between two views of reinforcement in Sidman's avoidance procedure. According to Sidman's most recent statements (1962, 1966), the avoidance response is maintained in his procedure because it reduces the frequency of occurrence of the electric shock. The responding, moreover, is distributed in time so as to be efficient, by which Sidman means that responses tend to achieve a maximal delaying of shock and thus a maximal reduction in shock frequency. In contrast, Anger (1963) argued that the reinforcement for responding in Sidman's procedure is the elimination of stimuli that become aversive by pairings with the shock, and that these conditioned aversive stimuli are likely to be temporal. Anger's theory is a version of traditional two-factor theory (Mowrer, 1947), postulating as it does, first, some stimulus that becomes motivating as a result of pairing with shock and, second, reinforcement through removal of that stimulus.

As far as two-factor theory is concerned, the discrete-trial procedure, with the lever in the chamber, should be equivalent to Sidman's procedure. The conditioned stimulus may be presumed to be the stimulus-complex associated with the presence of the lever in the experimental chamber (including either buzzer-on or buzzer-off) plus the passage of time since the last shock or the most recent insertion of the lever. Twenty seconds from either event (whichever is the most recent) the rat is shocked if it does not press the lever. Applying Anger's (1963) reasoning to the present situation, one would conclude that as in Sidman's procedure, responses occurring late in the 20-sec period would be more strongly reinforced than responses early in the period because the former terminate stimuli more closely approximating the 20-sec interval that is paired with shock. Thus, it would seem that responding should gravitate toward the end of the 20-sec period, showing no worse evi-

dence for timing than in Sidman's procedure. If anything, timing should be more likely on the discrete-trial procedure, since the onset of a trial is marked by gross stimulus changes that would provide excellent anchor points for time-related stimuli.

In contrast, the discrete-trial procedure is critically different from Sidman's procedure, as far as Sidman's account is concerned (1962-1966). Since, for Sidman, the reinforcer is shock-frequency reduction, *which is equally produced by any lever response in the discrete-trial procedure*, there should be no timing in the distribution of responses. Although the theory does not explicitly say so, it implies that without this kind of timing, the responding in the discrete-trial procedure would be random.

The data are damaging to both theories. Neither with Sidman's procedure nor with the discrete-trial procedure is there a significant correlation between the occurrence of timing and the adequacy of the avoidance behavior. For both procedures, timing was somewhat labile, drifting in and out of focus without relation to any of the other parameters of the procedure, either shocks, stimuli, or other responses. At the same time, avoidance remained comparatively stable and at high levels of proficiency. Anger's theory in particular seems to be contradicted by this independence between responding and timing, for, as noted before, Anger has argued that the timing is inherent in the nature of the reinforcement for avoidance. Although the removal of conditioned aversive temporal stimuli ("CATS", see Anger, 1963) is not the only source of reinforcement for avoidance in Anger's theory, it is intended to be a major one, and so the independence between responding and timing in the two procedures studied here can only be viewed as damaging to Anger's theory. Sidman's theory, on the other hand, is confronted by the unmistakable evidence for timing with the discrete-trial procedure. According to Sidman's theory, timing may occur with his own procedure, but not with the discrete-trial procedure; according to Anger's, it should occur equally in both. Neither prediction is confirmed. On the one hand, timing is found with both procedures, but, on the other, it is not equally in evidence. The timing with the discrete-trial procedure was more labile, more prone to cyclical waxings and wanings, and appeared to differ in its pattern from the timing with Sidman's pro-

cedure even when present (compare Fig. 2 and 3).

Both Sidman and Anger assume that the reinforcer for timing is the same as that for responding; they just pick different reinforcers. For Sidman, timing and responding are both maintained by reductions in shock frequency; for Anger, by the removal of conditioned aversive stimuli. It is possible, however, that the tacit assumption is false, and that timing does not depend entirely upon the avoidance contingency but on other factors in the situation or in the animal itself. Trivially, responding is sure to be non-random, whatever the reinforcer for avoidance, for lever pressing physically cannot occur with the infinitesimally short interresponse times and latencies called for by a strict interpretation of mathematical randomness. Less trivially, animals may tend to respond with long latencies or low rates so long as these produce no drastic consequences, just as they tend toward the least effortful responding that reinforcement contingencies permit (Herrick, 1964). Some such source of timing, unrelated to the avoidance contingency, is implicated by the independence between timing and proficiency of avoidance, found here with both Sidman's procedure and the discrete-trial procedure. This independence was seen in the pooled data plotted in Fig. 4, describing an animal whose IRTs/op curves swung widely while it continued to avoid nearly all shocks throughout.

The independence of timing and avoidance, both between and across animals, is strikingly portrayed by the patterns in the oscilloscope pictures shown in Fig. 5 to 8. Here are data from a group of animals, all avoiding, but showing a variety of response patterns—bimodal, unimodal, or neither; homogeneous or inhomogeneous; cyclical, random, one or the other, or neither. Yet, as regards summary measures of performance, such as the conditional probability distributions, all animals were well within the norms reported in the literature. In virtually every way, the most variable aspect of performance here was the temporal microstructure, and there is every reason to suppose that this has also been true in earlier studies of Sidman's procedure. For this reason alone, one may doubt the common origin of timing and avoidance; hence the theories that are predicted on this common origin.

A few final comments are in order regarding specific features of the discrete-trial procedure and some of its results:

(1) This procedure bears a relation to Sidman avoidance that is analogous to the relation between Logan's discrete-trial DRL procedure and standard DRL procedures (Logan, 1961). In both cases, the discrete-trial procedure is formally equivalent to the related free-operant procedure if the inter-trial intervals are deleted; in both cases, responding on the discrete-trial procedure lacks the extremely short-latency responses that consistently appear on the free-operant procedure.

(2) Wertheim (1965) presented selected data on sequential dependencies of IRTs on a Sidman avoidance procedure with $RS = 20$ seconds, and with $SS = \text{zero}$. He found systematic shifts in IRTs that resemble those sometimes seen in the oscilloscope pictures on the present discrete-trial procedure; *i.e.*, systematic increases in probability of response with time since the preceding IRT or latency, with time since the preceding shock, and with time since the beginning of the session. These patterns were notably absent in the oscilloscope pictures taken during Sidman avoidance with $SS = 20$ sec, suggesting that Wertheim's procedure, with the SS interval equal to zero, is more similar to a discrete-trial procedure than it is to the more usual Sidman procedures, with SS -intervals substantially greater than zero.

(3) The discrete-trial procedure arranges an inverse correlation between response latency and the time between response and subsequent trial. This correlation is required if the number of responses is to equal the number of shocks avoided over a session of fixed duration. If the temporal distribution of responding had been allowed to alter the session duration (for example, by using a fixed-duration intertrial interval), then the discrete-trial procedure would not have controlled for the key feature of Sidman's procedure as far as Sidman's theory is concerned. By keeping the sum of the response latency and the intertrial interval constant (20 sec), the discrete-trial procedure prevents the differential reinforcement of timing. As far as two-factor theory is concerned, the variable intertrial interval should make no difference, for the aversiveness of the conditioned stimulus depends solely upon its pairing with the shock. The fact that timeout

duration (hence, the duration of an intertrial interval) has been shown by others (Verhave, 1959; Sidman, 1962b) to be a factor in the reinforcement of avoidance behavior is itself evidence against the ability of two-factor theory to define the substantive issues in avoidance.

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