*SOME SEQUENTIAL ASPECTS OF IRTs EMITTED
DURING SIDMAN-AVOIDANCE BEHAVIOR IN
THE WHITE RAT^{1,2}*

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This study investigated some of the serial patterns among interresponse times during Sidman avoidance. It was found that the momentary probability of a response was determined by the length of exposure to the avoidance procedure during a session, by the time since the last shock, and by the duration of the preceding IRT.

An adequate description of Sidman-avoidance, in which the next shock is due a fixed time after the last response (Sidman, 1953), would include an identification of the reinforcing events for the avoidance response, and an indication of how accurately a given event sequence (e.g., a particular series of responses and shocks) may be predicted. Many experimenters have studied the interresponse time (IRT), defined as the time elapsing between two successive responses, in order to infer some aspects of the controlling variables during free-operant avoidance. One such use of the IRT (Sidman, 1954) showed that during the acquisition of Sidman avoidance behavior, the relative frequency distribution of IRTs was closely approximated by a theoretical negative exponential distribution. As Mueller (1950), Sidman (1954) and others have shown, the exponential distribution is consistent with the assumption that successive IRTs are

emitted randomly in time, i.e., that IRT emission is a Poisson process (cf. Kendall and Stuart, 1963).

Subsequent experimentation has indicated that the assumption of random emission does not furnish a wholly adequate description of Sidman avoidance behavior. For example, the conditional probability of an IRT less than $t + \Delta t$ given that it is longer than t is not a constant (as in a Poisson process) but instead increases as the time of the next due shock nears (e.g., Anger, 1956). On the basis of such results, Anger (1963) concluded that the stimuli immediately following an avoidance response are less aversive than stimuli further removed in time from the last response and hence closer to the next due shock. A problem with such a description is that the hypothetical temporal stimuli are unobservable. This difficulty would be partly overcome if sequences of successive IRTs were recorded; if temporal stimuli control performance, then stable temporally-defined response sequences (chains of IRTs) should be apparent. Such measurement would allow some prediction of the time to the next event, and of whether the next event would be a response or a shock.

The purpose of the present experiment was to examine in detail some of the temporal sequences of responding during Sidman avoidance. It was anticipated that the successive IRTs would exhibit sequential dependencies or trends. A quantitative description of these dependencies would extend the range of empirical findings on the determinants of momentary response probability during Sidman avoidance conditioning, as well as to further define the necessary scope of a theory of the IRT emission process.

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In order to study sequential properties of IRTs, three rats were given extensive training on Sidman avoidance. Sidman's basic procedure was followed, except that an escape response was required to terminate the shock, whereas in the original procedure each shock was of a fixed 0.2-sec duration.

METHOD

Subjects

Three naive female adult white rats, selected from the colony maintained by the Stanford University Psychology Department, were maintained at *ad libitum* body weight in individual living cages.

Apparatus

The experimental chamber was a standard Foringer rat box. The lever, mounted on a telegraph-key base, activated a normally-open microswitch contact to indicate responses when depressed through a distance of 0.25 in. The stimuli were programmed and the responses recorded by automatic switching circuits. The shock, delivered to the grid floor and to the lever, was at a level of 1.3 ma, at 350 v dc. A scrambler reversed the polarity of the shock on each grid bar at a rate of 15 times per sec. The IRT sequences were recorded on an Esterline-Angus 20-channel event recorder. Each channel of this device recorded the occurrence of a particular IRT.

Fig. 1. Frequency distribution of the time intervals between successive responses. The three panels in each row cover the three 20-min segments of each session. The intervals are coded along the abscissa, so that 1 represents the first IRT interval (0-2 sec), 2 the second IRT interval (2-4 sec), etc.

Fig. 2. The percentage of IRTs greater than t sec. The line through the data is a plot of the equation for a Poisson process (see text). The order of the panels corresponds to that in Fig. 1.

Procedure

The Ss learned to avoid shock via a modified Sidman technique (Sidman, 1953). Each lever-press response postponed shock for 20 sec, the response-shock (RS) interval. Once the shock was turned on, a lever-press was necessary to turn it off; this escape response also began the next RS interval. Only the initial downward press on the lever terminated or postponed shock; holding the lever down had no effect on shock occurrence.

Each session was approximately 1 hr in length. They were conducted on consecutive days over a period of five months, except for occasional days of apparatus repair.

RESULTS

The results reported are from a single representative session for each S. These data were

obtained after sufficient prior conditioning (approximately 30 hr per S) so that the Ss' overall response rates were stable. During conditioning, the shock escape latencies were uniformly short, averaging 0.1-0.2 sec. Such quick escape responding developed early in conditioning in all Ss and remained a stable feature of all subsequent sessions.

One description of the behavior is provided by plots of the frequency distributions of the IRTs. The IRT distributions obtained in successive 20-min intervals of the session are shown in Fig. 1, where one row corresponds to each of the three Ss. Figure 1 reveals that the shape of the IRT distribution changes during the session, and that the changes are similar for all three Ss. Warm-up effects are prominent during the first 20 min, in that the most frequent IRTs are those in the shortest (burst) interval and those in the longest

(shock-escape) interval. During the second 20 min (the middle column of Fig. 1) the frequency of shocks is lower but the burst frequency remains high, and there is an increase in the frequency of IRTs other than bursts or shocks. This clustering at intermediate IRTs is more pronounced during the last 20-min period: shocks and bursts decrease, and widely-spaced responses are the dominant feature of the distributions of S-76 and S-79. The modal avoidance IRT of S-17 is shorter than that of S-76 and S-79, but this S's data reflect the general trend toward a decrease in the number of shock and burst IRTs and an increase in the number of intermediate-length avoidance IRTs.

In Fig. 2, the IRT distributions appear in the cumulative form utilized by Sidman (1954). This depicts the percentage of IRTs greater than t sec. An equation for a random (Poisson) process, $P(IRT > t) = e^{-pt}$, has been fitted to the data. $P(IRT > t)$ is the theoretical probability that an IRT will be greater than t sec, e is the base of Napierian logarithms, and p is a constant equal to the momentary probability of a response per second (which is proportional to the average response rate). A close fit of the theoretical function to the data would indicate that if the IRT distribution were considered in its entirety, then a valid description of the data would be consistent with the assumption that the momentary response probability is not a function of the time since the preceding response. If, for example, a data point lies below the theoretical curve at some point t , then the observed percentage of IRTs greater than t is less than theoretically expected, i.e., the percentage of IRTs less than t is greater than expected.

By visual inspection, the fit is poor in most of the cases, indicating that the Poisson assumptions are not satisfied. The systematic deviation of the early data from the predicted curves, in the left panels, reflects the very high frequency of bursts and very low frequency of intermediate IRTs. The later systematic deviation, in the right panels, indicates a very low frequency of short IRTs and a very high frequency of long IRTs. The abrupt dip in the observed functions at the longest IRT is a consequence of the escape contingency: if an IRT is greater than 20 sec, then a shock will occur which will immediately be followed by an escape response.

Figure 3 illustrates a sequential aspect of the present data, viz., that the lengths of successive post-shock IRTs depend upon the time (in terms of the number of intervening responses) since the last shock. Figure 3 depicts, for each of the Ss, the average IRT for the first seven or fewer successive post-shock avoidance responses, for all such sequences during the final half hour of the session. The curves reveal that after a shock the average IRT is very short, but that succeeding responses are spaced increasingly far apart. The average IRT sequence was carried out for only seven post-shock avoidance responses because shocks often occurred after this point. This measure of performance did not change greatly after the warm-up period ended. An accurate assessment of this index during warm-up prevented by the small number of long avoidance chains during this period.

Figure 3 shows the expected value of IRT_{n+k} , for $k=1, 2, \dots, 7$, given that IRT_n was greater than 20 sec, i.e., given that a shock occurred between IRT_n and IRT_{n-1} . It would likewise be of interest to examine the values of successive IRTs, IRT_{n+1} through IRT_{n+7} , for various values of IRT_n . These data would indicate, for example, whether the orderly

Fig. 3. Average IRT for the first seven or fewer successive post-shock avoidance responses during the last 30 min of the session.

sequence of IRTs (*cf.* Fig. 3) is replicated when IRT_n is not an escape response. In the present paper, this analysis is performed only for IRT_{n+1} , for all possible values of IRT_n . That is, given the value of the n^{th} in a series of IRTs, it was determined what would be the most likely value of the $n+1^{st}$ IRT. To do this, the frequencies were tabulated in a matrix for the number of times that IRT j was immediately followed by IRT k . Since there were 11 IRT values, each such transition matrix contained the total entries from $11^2 = 121$ possible unique transitions. Each column of such a matrix is a conditional probability distribution, and the 11th column contains the data for the calculation of the first point of a function such as those in Fig. 3. To

summarize the description of the set of 11 conditional distributions, the most likely (modal) values from each are plotted in Fig. 4. The abscissa of this figure represents the n^{th} in a series of IRTs; the point plotted is the modal IRT that follows it. In a number of cases, there were two distinct modes to the conditional distribution; in these instances, both points are plotted above the abscissa values. In all cases, over 80 per cent of the conditional frequencies are accounted for by the modal point(s).

Such matrices, unlike the data in Fig. 3, do not indicate in which order the successive responses were emitted, but rather what the next IRT is likely to be, given the value of the present IRT. If IRT emission were an independ-

Fig. 4. The modal probabilities of transition from one IRT (n) to the next IRT ($n+1$). The order of the panels corresponds to that in Fig. 1 and 2.

ent process, for example, then the transitions among the several IRTs would be identically distributed. That is, regardless of the value of IRT_n , there would be only one conditional probability distribution for IRT_{n+1} , so that the frequency with which any IRT would follow any other IRT would be a constant. The data show that in general the modal value of IRT_{n+1} depends on IRT_n . Thus, while the one-step sequences exhibit no simple order at the start of the session, the dependencies become more apparent during later parts of the session. For example, consider the first S's data (Fig. 4, top row). During the first 20 min, irrespective of the value of IRT_n , it is most likely that IRT_{n+1} will be either a burst or a shock. This is the kind of pattern to be expected during the warm-up period. During the second 20 min an orderly pattern has begun to develop: if IRT_n is 1 or 2 (0.2 sec or 2.4 sec), then IRT_{n+1} is likely to be either another short IRT or a shock (interval 11). However, the pattern for the next four IRTs indicates a progressive lengthening of IRT_{n+1} . The longer IRTs do not show this relationship; instead, for most of the long IRTs, the next response is likely to be either a burst or a shock. The orderly sequence of IRTs continues during the last 20 min of the session, during which IRT_{n+1} is most likely to be slightly longer than IRT_n for IRTs less than 9, while IRTs greater than 9 are likely to be followed by very short IRTs. This pattern is an extension of that seen in the preceding 20-min period, from which it differs principally in the decreased frequency of bimodality. These trends, which indicate that the transition from warm-up toward well-developed avoidance performance is characterized by increasing dependencies in the transitions among successive IRTs, are observed in the data of all three Ss.

DISCUSSION

In illustrating several aspects of momentary changes in response probability during Sidman avoidance, the results of the present study provide information relevant to the evaluation of various measures of free-operant performance and to the discussion of theories of the avoidance response process. It is apparent, from both the present data and those reported by Anger (1963), that Poisson assumptions do

not provide a realistic description of the IRT emission process. For example, the systematic pattern of deviation of the empirical from the theoretical curves (Fig. 2) shows that the momentary probability of a response (p) is some function of the time since the last response and of the duration of prior exposure to the avoidance procedure during the current session. A very similar pattern of such deviations was reported by Sidman (1954). Upon consideration of such data as these, as well as upon the observation (Anger, 1956; Sidman, 1958, 1962) that response probability during the RS interval is an increasing function of the time since the last response, Anger (1963) advanced an hypothesis on the nature of the reinforcing stimuli in Sidman avoidance. He proposed that avoidance behavior is reinforced by the termination of members of two classes of temporal aversive stimuli, post-shock-time (PST) stimuli and post-response-time (PRT) stimuli. Short PST and PRT stimuli are relatively "safe", since they are temporally remote from the next shock. PST and PRT stimuli that just precede the next shock are highly aversive due to generalization from the imminent shock. An avoidance response is reinforced by the substitution of novel PST stimuli for PST stimuli made aversive through prior pairing with shock, and by the substitution of short PRTs in place of longer PRTs.

The data in Fig. 3, however, suggest an alternative to one aspect of Anger's hypothesis, *viz.*, that short PST stimuli are relatively more aversive than longer PST stimuli. This suggestion is based on the assumption that a more aversive situation is more likely to produce an avoidance response. Figure 3 shows that the momentary probability of a response is a decreasing function of the length of the PST. This is readily understandable under the hypothesis that the aversive internal concomitants of shock (*e.g.*, emotional, motivational and pain stimuli) are only gradually reduced when the shock is terminated. Such a relationship would be consistent with the observation that a post-shock "extinction" effect has often been noted during early stages of Sidman avoidance conditioning (*e.g.*, Sidman, 1958). A similar result was demonstrated (Sheffield, 1948) in a discrete-trial situation in which a guinea pig received a shock unless its avoidance latency was less than a predetermined interval. After a shock the avoidance latency

was very short, but it gradually increased over successive avoidance (nonshock) trials. In another study, in which free-operant avoidance of an intense bright light was contingent upon continuous lever depression, Hefferline (1950, p. 271) inferred that the force exerted by the rat on the lever gradually decreased as the last light presentation became more remote in time. Hefferline (*op. cit.*) and Keller and Schoenfeld (1950) cite similar data obtained by Winnick. Hearst (in press) provides a review of similar experimental and theoretical treatments.

The present data do support Anger's hypothesis that long PRTs are more aversive than short PRTs. Figure 4 shows that during the last 20 min of the session, a short IRT is very likely to follow a very long avoidance IRT. That bursts are likely to follow long IRTs was also found by Sidman (1958). This oscillation in IRT length may be caused by a generalization from the consequences of a very long (shock-producing) IRT to the IRTs almost as long. That is, the stimuli attendant upon a long non-shock IRT may reintegrate the stimulus situation consequent to a maximal (shock) length IRT. Similar response oscillations were reported by Hefferline and by Winnick (*op. cit.*) in the lever-holding situation.

While some of the present data can thus be subsumed under modifications of Anger's theory, a concise and quantitative formulation of the Sidman-avoidance process is still conspicuously lacking. The present results supply suggestions toward such a future formulation. Thus, the data indicate that the time of a shock is a good reference point for the analysis of sequential properties of Sidman-avoidance behavior. For example, during the later parts of the session, given the IRT of the n^{th} post-shock response, $1 \leq n \leq 7$, then from the transition matrix the $n+1^{\text{st}}$ IRT could be accurately predicted. It is not the case, however, that the shock alone imposes the order in the transition matrix, since the transitions are most predictable in the last 20 min of the session, when the frequency of shocks is lowest. The present results also imply that IRT emission during Sidman-avoidance may be characterized as a perseverative process with a positive time error. That is, the transition matrices indicate that for most IRTs, IRT_{n+1} is

slightly longer than IRT_n . Thus, S acts as if to match the length of IRT_{n+1} to IRT_n (for IRTs less than 20 sec), but with a trend toward an overestimation of IRT_n . Hence, there is a slow drift of the mode of the momentary response probability distribution toward longer IRTs. The slow drift would be cyclic, such that the mode of the distribution would be reset to a short IRT either by a shock or by a long non-shock IRT. A mechanical analog of this process may be observed in the operant laboratory, where a defective recycling timer may produce successively longer cycles, and must be periodically reset by the experimenter. The utility of such descriptions, however, can be evaluated only by future experimentation in which a more comprehensive account is afforded the temporally-ordered event sequences during Sidman avoidance.

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