FREE OPERANT AVOIDANCE AS A FUNCTION OF THE RESPONSE-SHOCK = SHOCK-SHOCK INTERVAL¹

FOGLE C. CLARK AND LARRY D. HULL

EVANSVILLE STATE HOSPITAL

Two temporal parameters of free operant or Sidman avoidance behavior are the interval by which responses postpone shocks (Response-Shock interval) and the interval between shocks when no responses occur (Shock-Shock interval). Avoidance behavior was examined in three white rats under conditions where the Response-Shock and Shock-Shock intervals were always equal. With intervals from 10 to 60 sec response rates and shock rates were similar, decreasing, negatively accelerated functions of increasing Response-Shock = Shock-Shock interval. Over this range, response and shock rates were linearly related to the reciprocal of the Response-Shock = Shock-Shock interval. It was shown, however, that this relation cannot hold at extremely long intervals. Both the ratio of responses emitted to shocks received and the percentage of shocks possible which were avoided increased at long Response-Shock = Shock-Shock intervals. These findings may be related to the fact that long intervals provide optimal conditions for conditioning avoidance behavior in the rat.

Free operant avoidance responding as a function of the Response-Shock (RS) and Shock-Shock (SS) intervals was first investigated by Sidman (1953). He presented data on the rate of responding as a function of the RS interval with the SS interval as a parameter. Where stable avoidance behavior is desired for the purpose of investigating the effects of other variables, equal RS and SS intervals are commonly used. This, of course, reduces the equipment required to program an experiment. In some cases it may also have methodological advantages. For example, if a drug which decreases the response rate is administered, the shock rate may increase rapidly if the SS interval is smaller than the RS interval. The large increase in shock frequency which follows a lowered rate under these conditions may then have additional effects on behavior. Data on the effects of several RS = SS intervals in a single hooded rat have been reported by Verhave (1959a). The present experiment examines avoidance behavior in the rat under a fairly wide range of RS = SS intervals.

METHOD

Subjects

Three adult male Sprague-Dawley rats weighing about 500 g were selected from a large group of rats which had been run on avoidance schedules for other purposes. They were selected on the basis of their low shock rates at RS = SS = 20. The history of two subjects (RA-53 and RA-62) consisted entirely of 6-hr sessions under RS = SS = 20 sec run on alternate days. The third subject (RA-58) came to the RS = SS = 20 sec schedule after 36 sessions at RS = SS intervals of 60 sec or more.

Apparatus

Experiments were conducted in three cages 7½ in. high, 8 in. wide, and 9¼ in. long with a grid floor consisting of 16 stainless steel rods ⅛ in. in diameter (Scientific Prototype Model A-100). A Gerbrands lever was mounted 2 in. above the floor on the midline of the cage-end and required a force of 10 g for operation. Depression of the lever produced an audible click and a brief flash from a 1 in. diameter, red, 7 w pilot light in the cage lid directly over the lever. A 7 w house-light indirectly illuminated the cage area. White noise was present during sessions. Food and water were continuously available, since

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the subjects spent alternate days in their experimental cages. Cages were housed in insulated containers in a room adjoining the control and recording apparatus. Shocks were delivered from a Grason-Stadler shock generator and scrambler set for 1.0 ma maximum current and 0.5 sec shock duration.

Procedure

The rats were run on alternate days three days per week at RS = SS intervals of 10, 15,

20, 40, and 60 sec. RA-58 and RA-62 were run through these conditions in the order 20, 15, 10, 20 (recovery), 40, and 60. Animal RA-53 was not run at RS = SS = 15 sec but otherwise ran through the schedules in the same order. Sessions were 6 hr in duration except at RS = SS = 10 sec where duration was reduced to 5 hr because of the higher shock rate obtained at short RS = SS intervals. Data were analyzed from the last 4 hr of the last three sessions at each schedule, except where malfunc-

Fig. 1. Cumulative records of the performance of one rat under each schedule. Records have been broken into 1 hr segments (at which times the recorder was reset) and overlapped by 30 min. Slash marks indicate shocks. Entire sessions are shown, although only the last 4 hr of each were analyzed.

tions necessitated one or more additional sessions. The first schedule ($RS = SS = 20$) was run for 20 sessions, and the remaining schedules for eight or more sessions. Although an explicit criterion of stabilization was not used, the schedule for a given subject was not changed (with two exceptions) until the session response rates were within $\pm 10\%$ of three-day means.

RESULTS AND DISCUSSION

Responses and shocks were recorded on cumulative recorders. Responses were also printed out of a counter at the end of each hour. The mean rate of responding and mean shock rate over the last 4 hr of the final three sessions under each schedule were then determined.

Figure 1 shows cumulative records of the performance of one subject under each of the schedules used. In each case the entire session is shown, although only data from the last 4 hr have been analyzed. This subject (RA-58) had the highest shock rates obtained at the shorter $RS = SS$ intervals. The "warm up" seen in the first hour of these records is typical. This seems to require about the same time under all the schedules, so that many more shocks are received at the shorter $RS = SS$ intervals before an appreciable avoidance rate develops.

Figure 2 presents the rate of responding and Fig. 3 the shock rate as functions of the $RS =$

SS interval. Data from the second (recovery) series of 10 sessions at $RS = SS = 20$ sec have not been entered in the figures. This series was run as a check against the possibility that exposure to short $RS = SS$ intervals might have irreversible effects. No evidence of this was found. Response and shock rates for the last three days of the second series deviated unsystematically from the first series data by less than 8%, and exhibited the same order of variability.

In all three subjects, response rates (Fig. 2) and shock rates (Fig. 3) were monotonic decreasing negatively accelerated functions of the $RS = SS$ interval over this range of the independent variable. Similar functions were obtained by Sidman (1953) between rate of responding and RS interval with the SS interval as a parameter (where the two intervals were equal only at one point). Sidman's data also indicate clearly that the rate of responding decreases rapidly at short values of RS over a wide range of SS intervals. Hence a discontinuity in the curves of Fig. 2 could be expected at very short $RS = SS$ intervals. Herrnstein and Brady (1958) obtained similar changes in response rate with equal RS and SS intervals from 5 to 20 sec. Verhave's (1959a) hooded rat also gave a function similar to those in Fig. 2 when RS and SS intervals were always equal, as in the present experiment. Verhave's data extended from $RS = SS = 15$ sec to $RS = SS = 50$ sec. In addition, Verhave (1959b) reported another similar relation as a

Fig. 2. Rate of avoidance responding as a function of the $RS = SS$ interval for each subject. Each point is the mean for the last 4 hr of one session. Straight lines are drawn between the means of the three points obtained at each value of the independent variable.

Fig. 3. Obtained shock rates as a function of the RS = SS interval for each subject. The data are plotted in the same way as Fig. 2.

function of the RS interval with the SS interval fixed and with eight responses, rather than one, required to restart the RS interval. Only Verhave (1959a) has previously reported on shock rates as a function of RS or SS intervals. His data agree generally with those of Fig. 3, except that higher shock rates were obtained at 20 sec than at 15 sec, although the response rate declined over this interval. In connection with the shock rate data of Fig. 3, it should be noted that the largest differences between subjects occurred at RS = SS intervals below 20 sec.

Previous investigators have fitted response rates as a function of RS intervals to an hyperbola which is linear in log rate and log (RS-Constant) (Sidman, 1953), or to a logarithmic equation linear in rate and log RS (Herrnstein and Brady, 1958), or in rate and log (RS-Constant) (Verhave, 1959a, 1959b). Both log log and semilog plots of the points in Fig. 2 and Fig. 3 were examined. In terms of the relative magnitudes of residual variances there was little difference between the two kinds of function. In agreement with previous data, however, the log log plots showed less evidence of systematic non-linearity in the response rate data. On the other hand, because of the characteristics of semilog transformations, the semilog plots exhibit some important properties of the data which are not apparent from inspection of Fig. 2 and Fig. 3. For this reason, and not on grounds of goodness of fit, the semilog plots are presented in Fig. 4. Here, both response and shock rates are plotted on log scales as functions of

the RS = SS interval. The straight lines in Fig. 4 were determined graphically by the method of averages using the points at and below RS = SS = 20 sec as the upper swarm. As noted above, there is some systematic non-linearity in the response rates of Fig. 4, particularly those of rat RA-62. Because of the characteristics of the transformation, however, Fig. 4 shows some important properties of the relation between response rates and shock rates as functions of changing RS = SS intervals. If response and shock rates declined proportionately as the RS = SS interval increased, then all three pairs of lines in Fig. 4 would be parallel. This would correspond to a state of affairs under which the ratio of responses to shocks remained invariant under changes in the RS = SS interval. This is obviously true, if at all, only in the case of RA-53. In the other two subjects the shock rate functions have much larger negative slopes, indicating that shock rates decrease proportionately much faster than response rates as the RS = SS interval increases. In other words, the ratio of responses emitted to shocks received increases as a function of the RS = SS interval. In fact, this is also the case with the data of RA-53, although the increase in response-to-shock ratio is much less in this subject over the present range of the independent variable.

Although the lines in Fig. 4 account for a large portion of the variance in the dependent variables, there is evidence of systematic non-linearity, particularly in the response rate data. As noted above, log log plots were somewhat better in this regard. In either case, the

Fig. 4. Semilog plots of the response and shock rates of each animal as functions of the RS = SS interval. Straight lines were constructed by the method of averages as described in the text.

fits are poorer than the log log transformations presented by Sidman (1953) for response rate as a function of RS interval. The latter, however, were based on a three-parameter hyperbola. It was remarked above that other empirical equations have also been used to describe similar data. Obviously, all these different relations cannot hold. The available data appear insufficient to dictate a choice among them. In such cases an examination of possible alternative transformations of the independent variable may prove instructive. Thus, Herrnstein (1961) has recently uncovered some important relations between the rate of responding and the reinforcement rate under interval schedules of positive reinforcement. Some of these relations had been masked by the tradition of specifying the independent variable in terms of the interreinforcement interval rather than the rate of reinforcement. An analogous transformation would specify the present independent variable in terms of the maximum shock rate generated under a schedule when no avoidance responses occur. This is the re-

ciprocal of the RS = SS interval times a scale factor for the units of measurement. Such a transformation would rectify a simple hyperbola. In examining the consequences of this transformation particular attention may be given to the relations between concomitant changes in response and shock rates, since these have not been examined previously.

In Fig. 5 the response rates are plotted as a function of the maximum shock rate possible under each schedule. In Fig. 6 the obtained shock rates are plotted as a function of the maximum shock rate. In both cases straight lines join the means of the three points obtained under each schedule. Both response and shock rates approximate linear functions of the maximum shock rate over this range of the independent variable. Neither Fig. 5 nor Fig. 6, however, suggest zero intercepts. Linear extrapolation of the data in Fig. 5 would give a large positive intercept for the response rate at zero maximum shock rate (avoidance extinction). This indicates that the linear relationship of Fig. 5 must break down

Fig. 5. Response rates as a function of the maximum shock rate possible under each schedule. Straight lines join the means of the three sessions obtained at each value of the independent variable.

at very small values of the maximum shock rate (*i.e.*, at very long RS = SS intervals). Thus, while substantial levels of responding can be maintained by very infrequent shocks (*e.g.*, Boren and Sidman, 1957), avoidance extinction is a well established experimental fact. Hence, the response rates in Fig. 5 must approach zero as the maximum possible shock rate becomes very small. In other words the lines in Fig. 5 must become concave downward at smaller values of the independent variable.

Fig. 6. Obtained shock rates as a function of the maximum shock rate possible under each schedule.

This downward concavity is already apparent in the data of subjects RA-53 and RA-58 between 60 and 90 shocks per hr. Somewhat similar reasoning leads to the conclusion that the relation between shocks received and shocks possible (Fig. 6) must become non-linear if extended over a sufficient range of the independent variable. Linear extrapolation of the data in Fig. 6 would give slightly negative intercepts for each subject. But the frequency of shocks received must approach zero as the maximum shock rate decreases further. Thus, the slope of the functions in Fig. 6 must be expected to decrease at very small values of the maximum shock rate, whereas the slopes in Fig. 5 must increase at very low shock rates. At low maximum shock rates, then, the ratio of responses emitted to shocks received should be large. In other words, the highest response-to-shock ratios are to be found at long RS = SS intervals. As noted above, this ratio increases markedly as a function of the RS = SS interval in two animals over the present range of the independent variable. Decreasing slopes in Fig. 6 at low maximum shock rates would also imply that a higher per cent of shocks possible be avoided at long RS = SS intervals. That is, if the slope of the functions in Fig. 6 decreases as the maximum shock rate approaches zero, then the ratio of ordinate to abscissa will decline at small values of the maximum shock rate. Again, there is a slight decrease in the ratio of shocks received to shocks possible with increasing RS = SS interval in the present data, except in the case of RA-53.

The results of this experiment appear to support three conclusions:

(1) Equality of RS and SS intervals yields a relation between the obtained shock rate and the RS = SS interval which is quite similar to that between the response rate and the same independent variable. It seems unlikely that the relation between response and shock rates can be as simple where the RS and SS intervals are unequal. Under such programs both responses and shocks, in effect, change the schedule.

(2) As the RS = SS interval increases, the ratio of response rate to obtained shock rate increases (or, more responses are emitted per shock received).

(3) As the $RS = SS$ interval increases the ratio of shocks received to shocks possible decreases (or, a higher proportion of shocks is avoided).

Although the available data appear to favor some sort of hyperbolic function, the exact form of relation between response and shock rates and the $RS = SS$ interval remains unsettled. The present data do, however, indicate—particularly as presented in Fig. 5 and 6—some of the properties that such functions must have. These data also indicate the importance of doing further research with an even wider range of intervals, and of examining variables such as the response-to-shock ratio. In this connection it should be remarked that current theories of the maintenance of free operant avoidance (Schoenfeld, 1950; Dinsmoor, 1954; Anger, 1963) make no quantitative predictions which would provide rational equations for the relations being considered.

Finally, the present data have some practical implications relating to the reliability of conditioning avoidance behavior in rats. Some rats commonly fail to condition under schedules involving RS and SS intervals of about 20 sec. The experience in this laboratory is that about 20% of rats conditioned under $RS = SS = 20$ sec will fail to develop low shock rates. With shorter RS and/or SS intervals the failure rate is much higher. With a light shock and sessions at least 6 hr in duration, however, we have never seen an animal fail to condition within the first session under $RS = SS$ intervals of 60 sec or more. Thus, fairly long $RS = SS$ intervals appear to be optimal for the conditioning of avoidance behavior in the rat. The last two conclusions

stated above may be related to this. That is, it appears that the schedule conditions which lead to the most reliable conditioning are also those which produce higher response-to-shock ratios and a higher percentage avoidance of total shocks possible under the schedule. These are notably not the conditions which maintain high avoidance response rates (and produce fast acquisition in those cases where conditioning does take place). Again, current theories of avoidance behavior make no direct predictions regarding the optimal parameters for conditioning.

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