FACILITATION AND SUPPRESSION OF RESPONDING UNDER TEMPORALLY DEFINED SCHEDULES OF NEGATIVE REINFORCEMENT¹

RONALD M. KADDEN²

FRANKLIN D. ROOSEVELT VETERANS ADMINISTRATION HOSPITAL
MONTROSE, NEW YORK

Two parameters for scheduling aversive stimulus presentations were studied systematically by specifying concurrent and independent probabilities of electric shock delivery for the occurrence and for the non-occurrence of a lever-press response. After preliminary training on a free-operant shock-avoidance schedule, 16 rhesus monkeys were divided into four groups, each group being assigned one shock distribution on a continuum from fixed interval to a widely ranging variable interval. Within groups, each subject was successively exposed to three values of response-dependence of shock delivery on a continuum from response-independent shock to complete dependence of shock on response occurrence ("punishment"). Introduction of shock following avoidance training produced initial response facilitation followed by suppression. Responding during both the facilitation and suppression periods was maximal when the shock schedule was periodic and response independent. Responding decreased as the inter-shock intervals were made more variable across groups, and as shock delivery was made increasingly response dependent within individual subjects.

The intrusion of aversive stimuli upon behavior maintained by aversive consequences has had the effect of either reducing or increasing response rate. Recently, attention has been focused on the schedule of aversive stimulus (S^{-R}) presentation as an important determinant of response-rate effects (Morse and Kelleher, 1970). The present paper attempts to analyze the role of S^{-R} presentation schedules in the maintenance and suppression of responding. The analysis makes use of an organizational scheme that integrates some previously employed schedules by making stimulus presentation dependent upon two behavior categories, responding and the absence of responding.

Stimuli that impinge upon a behaving organism interact with all behaviors, not only with

those arbitrarily selected for measurement. All behaviors that do not fall within a specified response class, R , may be included within a second class called "not-response", or $\bar{R}$. The classes R and $\bar{R}$ are mutually exclusive, and include all behaviors of the responding organism within any given time segment (Schoenfeld and Farmer, 1970). Stimulus presentation may be dependent upon behavior in either class, and a variety of reinforcement schedules may be described by manipulating the probabilities of stimulus presentation for R and $\bar{R}$.

Since these two probabilities can be varied independently of each other, their ranges of values may be represented by a set of orthogonal coordinates such as those in Figure 1. The space included within the axes defines all possible combinations of probabilities of S^{-R} presentation, given the occurrence of R , $p(S^{-R}|R)$, and $\bar{R}$, $p(S^{-R}|\bar{R})$, thus mapping a comprehensive domain of S^{-R} presentation schedules. In the region where $p(S^{-R}|\bar{R}) > p(S^{-R}|R)$, the frequency of S^{-R} presentation is reduced by the occurrence of R , whereas in the region $p(S^{-R}|\bar{R}) < p(S^{-R}|R)$, responding causes an increase in S^{-R} frequency. For $p(S^{-R}|\bar{R}) = p(S^{-R}|R)$, S^{-R} frequency is independent of responding; S^{-R} will follow either R or $\bar{R}$. Thus, a continuum of response-dependence of S^{-R} presentation is defined in moving between the lower right and upper left regions on the coordinates of Figure 1. Simi-

¹Portions of this study were reported at the meeting of the American Psychological Association, Washington, D. C., September, 1971. The data are based on a dissertation submitted to the Department of Psychology, Columbia University, in partial fulfillment of the requirements for the Ph.D.

²The author wishes to thank Professor W. N. Schoenfeld and Dr. A. G. Snapper for their advice and guidance throughout the course of this study. The study was supported by the National Institute of Mental Health under Grant MH-13049 to Dr. Schoenfeld, and by the Veterans Administration. Reprints may be obtained from the author, Psychology Research Laboratory, Building 7, Room 5, FDR VA Hospital, Montrose, New York 10548.

larly, continua of intermittency of S^{-R} presentation are defined between 0 and 1 on the two probability coordinates (*cf.*, Catania, 1971; Church, 1969; Gibbon, 1970; Seligman, Maier, and Solomon, 1971).

One specific way to manipulate probability of aversive stimulus presentation for R and $\bar{R}$ is to define a repeating time cycle, T, which can be subdivided into t^D and t^A portions (Schoenfeld, Cumming, and Hearst, 1956). Within the t^D portion of each T-cycle, one probability of stimulation is applied to the first R (Farmer, 1962; Millenson, 1963), or, given that the specified R has not occurred, another independent stimulus probability is applied to $\bar{R}$ at the end of t^D . Behavior during t^A has no scheduled consequences. Thus, R and $\bar{R}$ are defined only with respect to the t^D portion of each T-cycle.

The distribution in time of S^{-R} within an experimental session is a function of T and p. The value of T specifies the minimum time interval separating S^{-R} availabilities, and $1/p$ specifies the expected mean number of these intervals separating S^{-R} presentations. Hence, T/p represents the expected mean temporal interval between S^{-R} presentations. For successive occurrences of either R or $\bar{R}$, the mean interval is expressed by either $T/p(S^{-R}|R)$ or $T/p(S^{-R}|\bar{R})$ respectively. S^{-R} distribution can be manipulated, without affecting the frequency of S^{-R} , by adjusting T and p conjointly, holding T/p constant (Ferraro, 1967). When both R and $\bar{R}$ occur within an experimental session, the obtained frequency and temporal distribution of S^{-R} will depend both upon the assigned $T/p(S^{-R}|R)$ and $T/p(S^{-R}|\bar{R})$ values, and upon the actual frequencies of R and $\bar{R}$ (Schoenfeld and Cole, 1970).

In the present study, response rates in four groups of rhesus monkeys were compared across a continuum of shock periodicity ranging from fixed interval to variable interval, arranged by assigning each group different values of $p(S^{-R}|R)$ and T. Probability of shock for $\bar{R}$ was manipulated sequentially within subjects, producing degrees of response contingency of shock ranging from response-independent shock to punishment. Responding was first maintained on an avoidance schedule that was discontinued during tests of the T and p variables, but was reinstated between test phases.

METHOD

Subjects

Sixteen male rhesus monkeys (*Macaca mulatta*), all experimentally naive, served. Their age was estimated at between 3 and 4 yr. Their daily diet consisted of two meals of primate biscuits and fruit, and continuous access to water.

Apparatus

For the duration of the experiment, the animals were restrained in BRS-Foringer Rhesus Test Chairs that were installed in isolation booths. Each booth was equipped with an exhaust fan, a 7.5-W overhead lamp, and an overhead speaker. The lamp and white masking noise were turned on for the duration of each session. Two white indicator lights were mounted in front of the animals above eye level, and were illuminated for the duration of each response. The response manipulandum consisted of a wobble stick that closed a set of contacts upon movement at any angle from the center position (General Electric, No. CR104G29). During experimental sessions the wobble stick was located at thoracic level about 6 in. (15 cm) in front of the animal.

Electric shocks were delivered to a shaved portion of the tail through strips of aluminum foil held securely in place by Velcro straps. Electrode jelly was used to improve electrical contact between the foil and the tail. Constant current ac shocks were generated by passing the output of a 650-V transformer through a pair of matching capacitors. A switching circuit, which limits switching transients, was employed, as suggested by Ramsay, Knapp, and Zeiss (1970), in which the normally closed contacts of a relay short out the subject until shock delivery, at which point the contacts open, and the subject alone remains in the shock circuit. To eliminate residual switching transients entirely, shock onset and offset were delayed by means of a synchronous switch so that each occurred only at zero volts on the ac voltage cycle. Shock intensity was set at 13.5 mA, and duration at 300 msec.

All experimental contingencies and data recording were controlled on-line by a PDP-8 computer that was specially programmed for controlling behavioral experiments (Snapper and Kadden, *in press*). Responding was also monitored on Gerbrands cumulative recorders.

Procedure

The subjects were placed in restraint chairs for an initial acclimatization period, following which they were tested six days each week.

The initial experimental session was devoted to response shaping. For the next 18 sessions, a behavioral baseline was established for all animals on an adjusting avoidance schedule similar to the one described by Field and Boren (1963). This schedule was chosen because experience has shown that behavior under its control is characterized by rapid acquisition and low shock density. The schedule is a free-operant one that permits the shock-free time earned by each response to be added to any remaining shock-free time that was earned by previous responses, up to some maximum value of timeout from shock. In the present case, the unit amount of timeout earned by each response was 10 sec, and these timeouts could be accumulated up to a maximum value of 90 sec. The time values were selected to produce intermediate response rates, so that either facilitation or suppression could be obtained under the various schedules of shock presentation that followed avoidance. The shock-shock interval, if no response followed a shock, was 2 sec. Session duration was 150 min. The adjusting avoidance schedule was discontinued during testing of the T and p variables.

After exposure to this baseline, the animals were divided into four groups, equated as nearly as possible for mean response rate on the last day of avoidance baseline. Each group was then assigned one value of $p(S^{-R}|R)$: 0.1, 0.4, 0.7, or 1.0. To provide varying intershock time distributions with equal shock rates across groups, T -cycle durations corresponding to the four $p(S^{-R}|R)$ values were set at 1, 4, 7, and 10 min respectively. The value of $T/p(S^{-R}|R)$ was thus held constant at 10 min for each group for the duration of the study; the only experimental manipulation within subjects was made on the value of $p(S^{-R}|R)$.

Each T cycle was subdivided as follows: The first portion was t^A , in which no response of the subject had scheduled consequences. The last 6 sec of each T cycle was t^D , this duration being chosen on the basis of experience as one that would make it possible for both R and $\bar{R}$ events to occur in each session. The duration of t^D was held constant across groups and

Fig. 1. Orthogonal coordinates defining the possible combinations of the probabilities of aversive stimulus (S^{-R}) presentation given the occurrence of a response (R) or a failure to respond ($\bar{R}$), for all p . The diagonal is the locus of $p(S^{-R}|R) = p(S^{-R}|\bar{R})$. Circles represent probability combinations actually tested. Dashed lines between circles represent within-groups comparisons, and the solid lines between circles represent between-groups comparisons.

through all phases of the experiment to maintain equivalence of $\bar{R}$ for all conditions. The first wobble stick response occurring in t^D was defined as R and was shocked immediately upon occurrence with probability $p(S^{-R}|R)$. No further behavior of the animal had any scheduled effect in the given T cycle. If no wobble stick response occurred within t^D , this fulfilled the criterion for $\bar{R}$, and shock was delivered at the end of t^D with probability $p(S^{-R}|\bar{R})$. The values of $p(S^{-R}|R)$ and T -cycle duration were fixed for each group throughout the experiment, while $p(S^{-R}|\bar{R})$ took on different values within each group at different phases of the experiment. In the first phase, $p(S^{-R}|\bar{R}) = p(S^{-R}|R)$, then $p(S^{-R}|\bar{R}) = \frac{1}{2}p(S^{-R}|R)$, thirdly $p(S^{-R}|\bar{R}) = 0$, and finally the initial phase, $p(S^{-R}|\bar{R}) = p(S^{-R}|R)$ was repeated. Figure 1 shows the relationships among these probability combinations. The probability values to which each separate group was exposed in successive phases are connected by dashed lines. Each phase was conducted for 18 sessions, followed by six sessions of return to the adjusting avoidance baseline.

The parameter $p(S^{-R}|\bar{R})$, as defined in the current procedure, produced varying degrees of response-dependence of S^{-R} . In the first experimental phase, shock delivery was response-independent; in the second phase,

Table 1
Summary of Experimental Procedures

Subject	T-cycle Duration (Minutes)	Number of T Cycles per Session	$t\Delta$ Duration (Minutes)	$p(S-R R)$	$p(S-R R)$ Value in Each Experimental Phase			
					First	Second	Third	Fourth
A-62 A-64 A-78 A-80	1'	150	54 sec	0.1	0.1	0.05	0	0.1
A-60 A-70 A-84 A-88	4'	37	3'54"	0.4	0.4	0.2	0	0.4
A-66 A-68 A-82 A-86	7'	21	6'54"	0.7	0.7	0.35	0	0.7
A-74 A-76 A-90 A-92	10'	15	9'54"	1.0	1.0	0.5	0	1.0

shock delivery was more probable for R than for $\bar{R}$, and in the third phase, R was the only necessary condition for shock delivery.

The parameters $p(S-R|R)$, $p(S-R|\bar{R})$, and T-cycle duration allowed differing temporal distributions of shock to be generated during experimental sessions. The actual shock distribution obtained within a given session resulted from the relative numbers of R and $\bar{R}$ cycles produced by a subject, interacting with the pre-specified T-cycle and probability variables.

Table 1 summarizes the procedure, listing for each animal the T-cycle duration, number of T cycles per session, duration of the $t\Delta$ portion of each T cycle, $p(S-R|R)$, and the different values of $p(S-R|\bar{R})$ in their order of occurrence through the experiment.

RESULTS

Avoidance Baseline Responding

During the initial phase of avoidance baseline training, response rates increased rapidly at first and then levelled off or declined somewhat. At the nineteenth session, the subjects were assigned to groups equated as nearly as possible for response rate. The mean rates for the groups, in order of increasing group $p(S-R|\bar{R})$ value were 13.8, 12.1, 13.7, and 13.8 responses per minute.

Following each 18-session experimental

phase, when the baseline avoidance schedule was reinstated for six sessions, response rates began at low values, with accompanying high shock rates. Response rates recovered quickly, however, often within the first session, and shock rates correspondingly declined. A two-way analysis of variance was performed on the individual avoidance response rates from the last session of each avoidance segment. No significant effects were found for groups of subjects ($p > 0.10$), successive exposures to the avoidance baseline schedule ($p > 0.50$), or interaction ($p > 0.50$). A similar analysis of the total number of shocks delivered in the last session of each avoidance segment showed no significant differences for groups of subjects ($p > 0.10$), successive exposures to avoidance ($p > 0.50$), or interaction ($p > 0.50$). Thus, the various probability procedures to which the animals were exposed had no significant effect on subsequent avoidance performance.

Response Rates

Figure 2 shows the response rates of individual animals for Sessions 14 through 109. When the shock delivery schedule was changed from adjusting avoidance to the response-independent $p(S-R|\bar{R}) = p(S-R|R)$ procedure, and when this latter procedure was reinstated at the end of the experiment, response rates increased during the initial sessions to rates higher than their immediately preceding

Fig. 2. Response rate for each subject in consecutive sessions beginning with the fourteenth avoidance baseline training session. Each data point represents the mean rate for one session. The subjects are arranged according to their $p(S^R|R)$ grouping, with each group shown in a separate row across the figure. Subjects were exposed for 18 sessions to the $p(S^R|R)$ values indicated in the upper margin, preceded by six sessions of avoidance baseline. The function for each subject is broken before and after each six-day avoidance baseline period. In some cases, fewer than 18 sessions were plotted due to apparatus failures or missing data.

avoidance baseline levels. Maximum rates were achieved within the first seven sessions. The maximum rate was observed to increase across groups with increasing regularity of shock delivery (increasing $p(S^{-R}|R)$ in Figure 2). After reaching a maximum, each subject's response rate then declined to a level equal to or below the preceding baseline level. Like the maximum rates, the asymptotic response rates reached by the various groups after 18 sessions also increased across groups as a function of increasing shock regularity. When $p(S^{-R}|R)$ was reduced to $\frac{1}{2}p(S^{-R}|R)$ following avoidance baseline recovery, initial response facilitation was reduced and suppression occurred more rapidly and was more complete than in the procedure where the two shock probabilities were equal. Subsequently, when $p(S^{-R}|R)$ was reduced to zero, changes in response rate over consecutive sessions were similar to those in the preceding phase.

Return to the initial phase, $p(S^{-R}|R) = p(S^{-R}|R)$, produced fairly stable responding, with less initial facilitation and less suppression after 18 sessions than upon initial exposure to this set of values.

The behavior of Monkey A-90 was not differentially controlled by the experimental conditions. After initial baseline training, this subject assumed a high response rate that was maintained for the remainder of the experiment. This behavior resulted in a zero shock rate during baseline recovery periods, and 14 to 15 shocks per session during all of the phases in which shocks could be response-produced. During these latter phases, shocks were delivered regularly at 10-min intervals for 72 sessions, but with no evidence of response patterning between shocks. There is no apparent reason why this animal's behavior differed so markedly from the others'.

In the next figure, response rate has been expressed relative to performance on the avoidance baseline procedure. This was done to correct for differences in avoidance baseline response rate, allowing direct comparison among groups of the facilitatory and suppressive effects of shock presentation. Response rate on the final session of avoidance baseline preceding the introduction of each new $p(S^{-R}|R)$ value was taken as the baseline measure, and daily response rates of each subject were expressed as percentages of the most recent baseline measure.

Figure 3 shows the effect of shock periodicity [represented on the abscissa by $p(S^{-R}|R)$] on the per cent of baseline responding measure for each group of subjects, with $p(S^{-R}|R)$, as varied within groups, shown in successive panels. Within each panel, the data are for the first six and last six sessions at each value of $p(S^{-R}|R)$. Corresponding points were shifted slightly in the horizontal direction to allow for overlaps of the interquartile ranges ($Q_3 - Q_1$) of the group rates at each point, which are shown by vertical lines.

The functions for the first six sessions (solid lines) indicate that response rates decreased as $p(S^{-R}|R)$ was reduced to zero. While initial response suppression was rapid in the $p(S^{-R}|R) = \frac{1}{2}p(S^{-R}|R)$ and $= 0$ phases, most of the subjects did show facilitation in the first or second session, however. Upon return to the $p(S^{-R}|R) = p(S^{-R}|R)$ procedure, three of the groups showed considerable recovery of responding, but the slope did not recover its initial value.

Response rates during each phase of the experiment decreased toward the end of 18 sessions (dashed lines), so that there was little overlap of interquartile ranges of the first and last six sessions. The major exception to this, the $p(S^{-R}|R) = 1.0$ group, showed considerable overlap at all experimental phases due to the fact that Subject A-90 maintained high response rates throughout the experiment.

A two-way analysis of variance was performed comparing the per cent of baseline responding data of the first six sessions at each point across groups and across treatments within groups. Due to non-homogeneity of variance, it was required that an obtained F reach the 0.01 level in order to report significance at the 0.05 level (McNemar, 1957). It was found that the effects of both treatments, $p(S^{-R}|R)$ and $p(S^{-R}|R)$, were significant at the $p < 0.05$ level, with insignificant interaction effects ($p > 0.25$). A similar analysis on the per cent of baseline responding data of the last six sessions yielded a significant $p(S^{-R}|R)$ effect ($p < 0.05$), but an insignificant $p(S^{-R}|R)$ effect ($p > 0.10$) and insignificant interaction ($p > 0.50$).

Temporal Patterns of Responding

Early in each new procedural phase, subjects showed indications of positively accelerated response patterns following shocked T

Fig. 3. Median per cent of baseline responding as a function of four $p(S^{-R}|R)$ values. Response rate for each session was expressed as a per cent of the rate on the most recent avoidance baseline session. Each point of the figure represents the median of these percentages for the four subjects in a group over the first six (solid lines) or last six (broken lines) sessions. Vertical lines represent extent of upper and lower limits of the interquartile range ($Q_3 - Q_1$) about each median. Corresponding points on each graph are slightly displaced to prevent overlapping of the interquartile ranges. The different panels represent the successive manipulations of the parameter ($p(S^{-R}|R)$).

cycles. In all cases but one, however, this type of pattern soon disappeared and was replaced by a pattern in which peak response rates occurred just after shock delivery. Following T

cycles in which no shock was delivered, responding occurred at a steady rate.

Figure 4 shows 100-min portions of cumulative records for one subject in each group from

Fig. 4. Cumulative records for a single subject in each group at $p(S^{-R}|R) = p(S^{-R}|R)$. The value of $p(S^{-R}|R)$ for each subject is given in the left margin. Two records are presented for each subject: the first contains the clearest examples of post-shock pausing by that subject; the second was chosen from a subsequent session in which post-shock bursts predominate. Session numbers (beginning with initiation of the shock probability procedure) are listed above each record. The pen was reset to baseline at shock delivery, except at two points indicated in the first record, where the pen was reset after reaching its maximum excursion. The slashes on the event line below each record indicate completion of T cycles. Segments shown are of 100-min duration (except for the 0.7 group, which is 98 min to allow a whole number of cycles). The subjects, reading from top to bottom in the figure, are A-62, A-70, A-82, and A-92.

the first phase, $p(S^{-R}|R) = p(S^{-R}|R)$. The first record in each of the four pairs contains at least some evidence of post-shock pauses preceding higher rates of responding. The three remaining subjects in each group showed even less evidence of initial positive response acceleration, although each subject did show it for one or two sessions. Thereafter, however, the pauses disappeared, and eventually the highest response rates occurred shortly after shock delivery, as shown in the second record of each pair in Figure 4. With decreasing values of $p(S^{-R}|R)$ and T, (i.e., as shock delivery became less periodic), less post-shock responding was observed toward the end of 18 sessions.

The cumulative records of Figure 4 were taken during exposure to $p(S^{-R}|R) = p(S^{-R}|R)$, the first procedure following avoidance baseline training for each group. As $p(S^{-R}|R)$ was reduced, the number of instances of positive curvature of responding within T cycles declined (data not shown).

Relative Number of R and R Cycles and Shock Rates

The number of T cycles in which a response occurred in t^D was greater at the beginning of each experimental phase and declined over 18 sessions. Analysis of variance showed that there were no significant differences ($p > 0.10$)

among $p(S^{-R}|R)$ groups in per cent of R cycles during the first session of each phase, and therefore the data of the groups have been pooled. At the first phase, $p(S^{-R}|R) = p(S^{-R}|R)$, responses occurred in t^D on 79% of the cycles on the first session, and as $p(S^{-R}|R)$ was decreased the proportion of R cycles was 50% and 44%, with a rise to 52% at the recovery point. In all cases, the R cycle rate decreased to below 20% by the last three sessions. The per cent of R cycles at any point is the difference between the per cent of R cycles and 100%. The data thus indicate that all subjects had similar exposures to the R and R shock probability contingencies at the beginning of each phase of the experiment.

Figure 5 presents the median number of shocks per session delivered to each group during the first three (upper panels) and the last three (lower panels) sessions of each successive phase of the experiment. Also included in each panel are the median number of shocks per session delivered as a consequence of R occurrence (the remainder of the shocks having been delivered for R). The median number of

shocks delivered in the avoidance baseline period immediately preceding each set of shock probabilities is included in the upper panels. The number of shocks produced by R and R reflect, at each stage of the experiment, the relative frequency of these two response classes. The greatest proportion of shocks at the beginning of each phase (upper panels) was delivered for R . The number of R shocks at the beginning of each phase (total shocks minus R shocks) was approximately equivalent to the number of preceding baseline shocks. Thus, initially the increase in shock rate above the prior baseline shock rate was due to shocks delivered as a consequence of R occurrence. As responding declined to low rates at the end of each procedural phase, total shock frequencies were determined to a greater extent by the $p(S^{-R}|R)$ value (lower panels).

DISCUSSION

Response Facilitation

The initial reaction to the presentation of shock on the probability schedules, following

Fig. 5. Median number of shocks per session for each group of subjects during the first three sessions (top row of panels) and last three sessions (bottom row of panels) of each phase of the experiment. The column headings indicate the successive phases. Both median total shocks per session and the median number of shocks presented as a consequence of responding (R) are plotted. In addition, the median total number of shocks per session during the immediately preceding three avoidance baseline sessions are also indicated in the top row of panels. Note that at $p(S^{-R}|R) = 0$, shocks were delivered only as a consequence of the occurrence of R .

exposure to free-operant avoidance, was response facilitation. The highest response rates were observed when both probability parameters were at their maximum values, $p(S^{-R}|R) = p(S^{-R}|R) = 1.0$, where responding was facilitated more during the early sessions and suppressed less after 18 sessions than at any other point. This point corresponds to the periodic response-independent shock delivery schedules employed in previous studies, and the results were similar. For example, the response facilitation during the first six sessions (Figure 3) equalled or exceeded the three- to four-fold rate increases obtained by Sidman, Herrnstein, and Conrad (1957) and Stretch, Orloff, and Dalrymple (1968), and the nearly two-fold increases obtained by Byrd (1969), Jones (1969), McKearney (1968), and Sidman, Mason, Brady, and Thach (1962).

Various hypotheses have been suggested to account for the facilitating effect of shock presentation. Azrin and Holz (1966), Church (1963), and Sidman (1966) have proposed that subjects show a response rate increase in circumstances of response-independent shock delivery because of discriminations learned during prior avoidance training. Herrnstein and Sidman (1958), Kelleher, Riddle, and Cook (1963), and Sidman, *et al.*, (1957) indicated the necessity of a history of avoidance responding as a prerequisite for response facilitation under unavoidable shock delivery. Recently, Hutchinson, Renfrew, and Young (1971) demonstrated acquisition of lever pressing in the presence of periodic response-independent shocks, and accounted for this result in terms of shock elicitation of responding. Based on this interpretation, it may be that facilitation of a previously trained response is due to response-eliciting effects of shock, interacting with the baseline behavior.

An empirical approach to the phenomenon of response facilitation due to shock delivery should include systematic study of the conditions of shock presentation. Hutchinson *et al.*, (1971) studied two parameters of shock presentation, showing the importance of shock intensity and frequency for the control of response rate. The present study indicates the importance of two other parameters, temporal distribution and response-dependence of shocks, thus extending the specification of stimulus scheduling parameters that control behavioral effects under shock presentation.

Response Patterning

Upon first exposure to a response-independent shock schedule, all groups exhibited positively accelerated response patterns between shocks for a few sessions. After 18 sessions of exposure to the shock schedule, however, responding in all but one animal occurred only after shock delivery. Schedules that resulted in more periodic shock distributions maintained responding for the longest periods (several minutes) following shock. Monkey A-90, the exception, maintained a high steady response rate, showing very little evidence of response patterns between shocks after 72 sessions of periodic shock presentations on an FI 10-min schedule.

Positively accelerated response patterning, called "scaloped" responding because of the appearance it makes on a cumulative response curve, was obtained in studies where procedures did not differ greatly from those in the present experiment. The duration of the avoidance training period in the present case was similar to that provided by Byrd (1969) and McKearney (1968), and the shock intensity was similar to that used by Stretch, *et al.*, (1968). Timeout following shock delivery was used in some experiments, but does not seem to be necessary for the development of scaloped response patterns (Byrd, 1969; Kop and Snapper, 1970; Stretch, *et al.*, 1968). Thus, although the parameters of the present schedules did not differ greatly from those in the experiments cited, and the initial results were similar, they differed considerably over the long term. It is possible that a species difference was critical, the best examples of scaloped response patterns having been obtained in squirrel monkeys. While some of the variables that control initial response facilitation have been examined in the present study, the factors responsible for the long-term maintenance of scaloped response patterns in the presence of a shock-presentation schedule require further investigation.

Parametric Control of Response Rate

The level of initial response facilitation decreased across groups as the inter-shock intervals were made more variable (decreasing $p(S^{-R}|R)$ and T), and also decreased within subjects as shock delivery was made increasingly response-dependent [decreasing

$p(S^{-R}|R)$]. In a parametric study, Azrin (1956) compared punishment schedules on the dimensions of response dependence and temporal predictability of shock presentation, superimposed on responding maintained by positive reinforcement. He found VI shock delivery to be more suppressive than FI, and response-dependent shocks more suppressive than those that were response-independent. Comparing the present results with those of Azrin (1956), suggests that an avoidance history raises the overall level of the initial reaction to a shock schedule, while maintaining the same relative response rate relationships across parameters. In this regard, Herrnstein and Sidman (1958) showed that the suppression obtained under punishment of positively reinforced responding could be changed temporarily to facilitation by giving avoidance training before punishment.

In the present experiment, as shock delivery was made increasingly response dependent (as $p(S^{-R}|R)$ was reduced to zero), response rates declined to very low levels for all groups. Sidman (1966) suggested that responding may eventually cease when extended exposure to unavoidable shocks is given. In the present case, however, it appears that responding was under control of the response-dependence variable, since the progressive decrease in response rates with reduced $p(S^{-R}|R)$ was reversed when shock probability was increased from $p(S|R) = 0$ to $p(S^{-R}|R)$.

At this final level of the $p(S^{-R}|R)$ parameter, each subject received a mean of 15 shocks per session, and response rate was facilitated nearly equally across groups. Response rates of the four groups of subjects were no longer differentially controlled by $p(S^{-R}|R)$, the shock distribution parameter, as they had been during the initial exposure to the response-independent shock procedure. During this initial exposure, total shock frequencies had been similar across groups, indicating that it was not shock frequency, but rather shock distribution, that controlled the observed differences in response rates. The loss of differential control of response rate upon replication of $p(S^{-R}|R) = p(S^{-R}|R)$, suggests that over the course of the experiment responding had become more dependent upon shock frequency than upon shock distribution. Thus, at the end of the study, 15 shocks elicited a fairly consistent amount of responding regardless of

their temporal distribution. Boren and Sidman (1957) and Sidman (1966) presented data indicating that repeated extinction of avoidance responding may cause emission of the response to become tied to shock delivery. This may account for the relative flatness of the function obtained upon replication of the response-independent shock procedure (Figure 3), and also the increase in responding over the $p(S^{-R}|R) = 0$ function.

In the present experiment, it is not possible to determine to what extent the decrease in slope of the $p(S^{-R}|R)$ functions (Figure 3) at the $p(S^{-R}|R) = \frac{1}{2}p(S^{-R}|R)$ and $p(S^{-R}|R) = 0$ points was due to repeated exposures to avoidance extinction, and to what extent it was due to the decrease in $p(S^{-R}|R)$ value. A further study in which the smaller $p(S^{-R}|R)$ values were presented first could resolve this question.

Avoidance Baseline Recovery

At all stages of the present study, responding under re-exposure to the avoidance baseline schedule was found to be independent of the preceding shock presentation procedures. This is in marked contrast to the finding of Sidman, *et al.*, (1962) who presented unavoidable shocks at 2-min intervals during avoidance extinction. They found that subsequent reinstatement of the avoidance contingency for a single session did not reinstate responding, despite a shock rate of three per minute. This lack of recovery may have been due to the previous high shock rate in avoidance extinction, which was five times greater than that of the present study. The adjusting avoidance schedule with a short shock-shock interval might have aided the recovery of baseline responding in the present study. Solomon and his co-workers have studied examples of severe suppression (Maier, Seligman, and Solomon, 1969) and have not usually found it to occur after an avoidance response has been well-trained. The present data are consistent with that finding: recovery of responding began in the first session, and none of the manipulated parameters affected this recovery.

REFERENCES

- Azrin, N. H. Some effects of two intermittent schedules of immediate and non-immediate punishment. *The Journal of Psychology*, 1956, 42, 3-21.
- Azrin, N. H. and Holz, W. C. Punishment. In W. K. Honig (Ed.), *Operant behavior: areas of research*

- and application. New York: Appleton-Century-Crofts, 1966. Pp. 380-447.
- Boren, J. J. and Sidman, M. A discrimination based upon repeated conditioning and extinction of avoidance behavior. *Journal of Comparative and Physiological Psychology*, 1957, 50, 18-22.
- Byrd, L. D. Responding in the cat maintained under response-independent electric shock and response-produced electric shock. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 1-10.
- Catania, A. C. Elicitation, reinforcement, and stimulus control. In R. Glaser (Ed.), *The nature of reinforcement*. New York: Academic Press, 1971. Pp. 196-220.
- Church, R. M. The varied effects of punishment on behavior. *Psychological Review*, 1963, 70, 369-402.
- Church, R. M. Response suppression. In B. A. Campbell and R. M. Church (Eds.), *Punishment and aversive behavior*. New York: Appleton-Century-Crofts, 1969. Pp. 111-156.
- Farmer, J. *Properties of behavior under random interval reinforcement schedules*. Unpublished doctoral dissertation, Columbia University, 1962. (A shortened version of this paper was published in *Journal of the Experimental Analysis of Behavior*, 1963, 6, 607-616.)
- Ferraro, D. P. Response suppression and recovery under some temporally defined schedules of intermittent punishment. *Journal of Comparative and Physiological Psychology*, 1967, 64, 133-139.
- Field, G. E. and Boren, J. J. An adjusting avoidance procedure with multiple auditory and visual warning stimuli. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 537-543.
- Gibbon, J. *Contingency spaces and random controls in classical and instrumental conditioning*. Paper presented at the meeting of the Eastern Psychological Association, Atlantic City, April, 1970.
- Herrnstein, R. J. and Sidman, M. Avoidance conditioning as a factor in the effects of unavoidable shocks on food-reinforced behavior. *Journal of Comparative and Physiological Psychology*, 1958, 51, 380-385.
- Hutchinson, R. R., Renfrew, J. W., and Young, G. A. Effects of long-term shock and associated stimuli on aggressive and manual responses. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 141-166.
- Jones, R. T. The effect of rate of delivery of response-independent shocks upon avoidance responding. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 1023-1027.
- Kelleher, R. T., Riddle, W. C., and Cook, L. Persistent behavior maintained by unavoidable shocks. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 507-517.
- Kop, P. F. M. and Snapper, A. G. *Temporal patterning of avoidance responding under response-independent shock as a function of baseline schedule*. Paper presented at the meeting of the Eastern Psychological Association, Atlantic City, April, 1970.
- Maier, S. F., Seligman, M. E. P., and Solomon, R. L. Pavlovian fear conditioning and learned helplessness: effects on escape and avoidance behavior of (a) the CS-US contingency and (b) the independence of the US and voluntary responding. In B. A. Campbell and R. M. Church (Eds.), *Punishment and aversive behavior*. New York: Appleton-Century-Crofts, 1969. Pp. 299-342.
- McKearney, J. W. Maintenance of responding under a fixed-interval schedule of electric shock presentation. *Science*, 1968, 160, 1249-1251.
- McNemar, Q. On Wilson's distribution-free test of analysis of variance hypotheses. *Psychological Bulletin*, 1957, 54, 361-362.
- Millenson, J. R. Random interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 437-443.
- Morse, W. H. and Kelleher, R. T. Schedules as fundamental determinants of behavior. In W. N. Schoenfeld (Ed.), *The theory of reinforcement schedules*. New York: Appleton-Century-Crofts, 1970. Pp. 139-185.
- Ramsay, D. A., Knapp, J. Z., and Zeiss, J. C. Transients in "constant-current" generators. *Behavioral Research Methods and Instrumentation*, 1970, 2, 122-123.
- Schoenfeld, W. N. and Cole, B. K. Behavioral control by intermittent stimulation. In R. M. Gilbert and J. R. Millenson (Eds.), *Reinforcement: behavioral analysis*. New York: Academic Press, 1972. Pp. 147-164.
- Schoenfeld, W. N., Cumming, W. W., and Hearst, E. On the classification of reinforcement schedules. *Proceedings of the National Academy of Sciences*, 1956, 42, 563-570.
- Schoenfeld, W. N. and Farmer, J. Reinforcement schedules and the "behavior stream". In W. N. Schoenfeld (Ed.), *The theory of reinforcement schedules*. New York: Appleton-Century-Crofts, 1970. Pp. 215-245.
- Seligman, M. E. P., Maier, S. F., and Solomon, R. L. Unpredictable and uncontrollable aversive events. In F. R. Brush (Ed.), *Aversive conditioning and Learning*. New York: Academic Press, 1971. Pp. 347-400.
- Sidman, M. Avoidance behavior. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 448-498.
- Sidman, M., Herrnstein, R. J., and Conrad, D. G. Maintenance of avoidance behavior by unavoidable shocks. *Journal of Comparative and Physiological Psychology*, 1957, 50, 553-557.
- Sidman, M., Mason, J. W., Brady, J. V., and Thach, J. Quantitative relations between avoidance and pituitary-adrenal cortical activity. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 353-362.
- Snapper, A. G. and Kadden, R. M. Time-sharing in a small computer based on a behavioral notation system. In B. Weiss (Ed.), *Digital computers in the behavior laboratory*. New York: Appleton-Century-Crofts, (in press).
- Stretch, R., Orloff, E. R., and Dalrymple, S. D. Maintenance of responding by fixed-interval schedule of electric shock presentation in squirrel monkeys. *Science*, 1968, 162, 583-586.

Received 7 June 1971.

(Final Acceptance 6 November 1972.)