DENSITY AND DELAY OF PUNISHMENT OF FREE-OPERANT AVOIDANCE¹

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In two experiments, the free-operant shock-avoidance behavior of rats was punished by electric shock. Two aspects of the schedule of response-produced shock were varied: the frequency of punishment over time (punishment density) and the temporal interval between the punished response and the punishment (punishment delay). The general finding was that response-produced shock suppressed avoidance responding under most of the density-delay combinations studied, and suppression increased as a function of increases in density and decreases in delay. Rate increases of small magnitude also were observed, usually as an initial reaction to the lesser densities and longer delays. Response suppression, while decreasing the number of punishment shocks received, also increased the number of avoidance shocks, so that the total number of shocks received usually was greater than the minimal number possible. The results were discussed from the standpoint of similarities between the effects of punishing positively and negatively reinforced behavior. The finding that subjects did not minimize the total number of shocks suggested that when avoidance behavior is punished, responding is controlled more by the local consequences of responding than by overall shock frequencies during the course of the session.

Punishment refers to an arrangement in which a stimulus produced by a response has the consequence of suppressing that response. Until recently, investigations of punishment have been mainly concerned with the effects of punishing positively reinforced behavior. Among the variables that have been identified as contributing to response suppression are characteristics of the schedule maintaining the punished behavior, as well as characteristics of the punishing stimulus, such as its intensity, delay, or schedule of presentation (*cf.* Azrin and Holz, 1966).

The present experiment was concerned with the effects of applying punishment contingencies to behavior concurrently maintained by negative reinforcement. By analogy with procedures conventionally used in studying punishment of positively reinforced behavior, the essential procedure was first to establish the to-be-punished behavior, in the present case behavior maintained by a free-operant shock-

avoidance schedule, and then to make electric shock contingent on responding.

Using the above procedure, Sandler, Davidson, and Holzsuh (1966) punished the free-operant shock-avoidance responding of monkeys with fixed-ratio schedules of shock punishment. Response-produced shock had the general effect of reducing avoidance rates, although transitory rate increases occurred when the punishment contingency first was introduced. Of interest was the finding that punishment reduced response rates to intermediate levels with the consequence that responding served to minimize the total numbers of shocks available from the combined avoidance and punishment schedules. A subsequent study using rats (McIntire, Davis, Cohen, and Franch, 1968) also observed decreased avoidance rates when fixed-ratio shock was made contingent on responding, but increased rates did not occur at any point, and punishment suppressed rates to the extent that total numbers of shocks exceeded the potential minimum. A third study, by Powell and Morris (1969), punished the avoidance responding of rats with a continuous schedule and varying intensities of punishment shocks. While small rate increases occurred initially, the more gen-

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eral effect of response-produced shock was to suppress avoidance responding. The extent of suppression and the numbers of avoidance shocks received increased as a function of increases in punishment-shock intensity.

In addition to the experiments already summarized, several recent studies have shown that response-produced shock can be used to maintain rather than suppress responding (Byrd, 1969; Kelleher and Morse, 1968; McKearney, 1968). However, no attempt is made to relate these findings to the present findings because of major differences in procedure, particularly with regard to the mode of introduction of response-produced shock and the subjects' experimental histories before this condition. Byrd (1969), for example, was able to train cats to produce shock through use of an extended procedure that involved transitions from an avoidance schedule to a schedule in which shocks were response-independent rather than avoidable and finally to a terminal schedule in which responses produced shocks on a fixed-interval basis.

The present study, which used rats as subjects, examined the contribution of two variables to the suppression of avoidance behavior by response produced shock: punishment density, *i.e.*, the frequency over time with which responses were punished, and punishment delay, *i.e.*, the temporal interval between the punished response and delivery of the punishing stimulus.

GENERAL METHOD

Subjects

Five male albino rats, obtained from the Holzman Co., Madison, Wisconsin, were about 11 weeks old at the start of the experiment. Throughout, they were housed in individual cages with free access to food and water.

Apparatus

Training was conducted in two standard lever-press units (Grason-Stadler, E3125A). The chamber of each unit, 11.5 by 9.25 by 7.5 in. (292 × 235 × 191 mm), was of plastic construction except for the metal grid floor and front and rear walls. The response lever was centered on the front metal wall. Charging of the grid was from a shock source (Grason-Stadler, E1064GS) that delivered current to different pairs of grid bars and the front wall in

rapid alternation. This arrangement, together with the brief duration of the shocks, made unscheduled avoidance of the shocks unlikely. Adjacent to the chamber was a speaker used to present a continuous masking noise and a lamp that illuminated the chamber. Each chamber was enclosed within a sound-attenuating ventilated chest.

Preliminary Training

Subjects were trained to lever press on a free-operant avoidance schedule (Sidman, 1953) in which the aversive event was a 1-ma electric shock of 0.3-sec duration. Lever pressing was established using shaping procedures in which approximations of a lever press or the lever press itself postponed the shock for 20 sec (the response-shock, or R-S interval) and each shock was followed 3 sec later by another shock if a response was not made (the shock-shock, or S-S interval). When the response was acquired, subjects were trained daily for seven 60-min sessions with R-S = 20 sec and S-S = 5 sec. During the next seven days, the session length was increased to 90 min and the R-S:S-S intervals were increased through the following steps: 40:10 sec; 40:20 sec; 60:20 sec, and finally 60:60 sec.

Punishment Training

For the remainder of the experiments, the baseline schedule was one in which R-S:S-S = 60:60 sec and sessions were 90-min long. When stable responding was attained on the baseline avoidance schedule, a concurrent punishment schedule was introduced in which responding also produced shocks of the same intensity and duration as the avoidance shocks.

The punishment schedule was varied in different phases of the investigation according to two parameters: density of punishment shock and delay of punishment shock. Density refers to the number of times that responses could be punished during each 90-min session. To vary punishment-shock density systematically, each session was divided into equal temporal intervals, and, except as noted below, the first response within each interval produced the punishment shock; subsequent responses within the same interval did not. In different phases of the experiment, intervals ranged from 0.5 min to 18 min in duration, thus creating a range of punishment rates

from two punishment shocks per minute to one punishment shock every 5 min. The schedule of punishment shocks was not a fixed-interval schedule because the start of the interval in which the first response was punished was timed from the onset of the previous interval rather than from the last punished response. This arrangement, by comparison with a fixed-interval schedule, has the advantage of maintaining a given average density of shocks when rates are low, so long as at least one response is made within each interval.

Punishment delay refers to the temporal interval ensuing from the punished response to the actual delivery of the punishment shock. In different phases of the experiments, the punishment shock produced by the response followed that response by intervals ranging from 0 sec (immediate punishment) to 60 sec. Because the punishment shock was delayed, the procedure made it possible for a response within a given density interval to deliver punishment shock in the next interval. In such cases, the punishment contingency in the second interval was not instituted until the prior punishment shock had been delivered.

When stable rates of responding were reached after a series of sessions with a given density-delay combination, punishment shocks were omitted and a new non-punished baseline was established. To hasten recovery from punishment effects, initial recovery training was with R-S:S-S = 60:10 sec. The S-S interval then was increased to 60 sec and training was continued to stability before the next density-delay combination was introduced.

The following stability criteria were used. Non-punished behavior was considered stable when the difference between the means for the first and last three sessions of six consecutive sessions was less than 10% of the mean for all six sessions. The same criterion was used to determine stability of punished behavior that was not markedly suppressed. When punished behavior was markedly suppressed, stability was deemed met when the subject's rate was less than 10% of prior non-punished rates for four consecutive days or less than 5% for two consecutive days.

All data analyses were based on the last 60 min of each 90-min session. Data collected for each session were total numbers of responses, numbers of avoidable shocks received, and the numbers of punishment shocks received.

EXPERIMENT I

Procedure

Subjects 1, 3, and 5 were used. The procedure held delay of punishment constant at either 20 sec (Subject 1) or 40 sec (Subjects 3 and 5) and varied punishment density from one punishment every 0.5 min to one every 18 min. Each set of observations with a given density was followed by a recovery period when avoidance responding was unpunished. Table 1 shows the densities studied with each animal, the number of observations with each density, and the order in which the densities were presented. For two subjects (Subjects 3 and 5), extreme suppression occurred during the first set of punishment observations (Number 1 in Table 1). Because these reactions were markedly inconsistent with subsequent observations, the points were redetermined and the second set of observations was used in the data analyses described below.

Table 1

Number of sessions under each condition and the order in which the conditions were presented (parentheses) in Exp. I.

Density	S1	S3	S5
	20-sec Delay	40-sec Delay	40-sec Delay
18 min	6 (5)		21 (7)
14 min	16 (8)		
9 min	14 (2)	8 (2)	22 (2)
6 min	10 (3)	13 (3)	6 (3)
5 min	9 (6)		
4 min			10 (4)
3 min	11 (4)	8 (4)	9 (1)
			12 (5)
1 min	6 (7)	12 (1)	12 (6)
		8 (5)	
1/2 min	4 (1)		

RESULTS

To avoid the complicating influences of warm-up, analyses were based on the last 60 min of each 90-min session. To be noted, however, is that the trends reported below for the last 60 min also were present during the first 30 min, but in a less regular manner.

Figure 1 shows response rates during the punishment phases relative to prior non-punished rates. Response rates for each animal were entered into the ratio, $B/A+B$, in which A was the stable non-punished rate and B the stable punished rate. This ratio can vary from

Fig. 1. Suppression ratios as a function of punishment density in Exp. I. Rates during the punishment phases are expressed relative to prior non-punished rates (punished/non-punished + punished) with a ratio of 0.50 indicating no suppression and a ratio of 0.00 indicating complete suppression. Ratios are based on the last 60 min of the 90-min sessions. Each curve summarizes the terminal performances of a given animal at the various density values indicated on the abscissa. Note that density is expressed in terms of the duration of the intervals in which the first response was punished; reading from left to right, densities ranged from 120 shocks per hr (interval = 30 sec) to 5 shocks per hr (interval = 18 min). Delay of punishment was 20 sec for S1 and 40 sec for S3 and S5.

0.50 (no effect) toward limits of 1.00 and 0.00 depending on the extent of relative increases or decreases in rate in reaction to punishment.

Figure 1 shows that the general effect of response-contingent shock was to suppress responding relative to prior non-punished performance, and that the extent of suppression increased as a function of increased punishment densities. In the cases of Subjects 3 and 5, trained with the 40-sec delay, density values in the range 4 to 18 min had little or no effect on response rates. The density of one shock every 3 min produced moderate suppression for these two subjects, and the density of one shock every 1 min produced the most marked suppression. A similar, but somewhat more extreme trend is apparent in the performance of Subject 1. This subject, trained with the 20-sec delay, showed no suppression with the density value of 18 min, moderate suppression in the range 6 to 14 min, and increasing degrees of suppression as the density was increased from one shock every 5 min to one shock every 1 min.

The data were examined also from the

standpoint of whether response-contingent shock produced, at any point, relative increases in rates rather than suppression. As Fig. 1 suggests, rate increases, *i.e.*, ratios greater than 0.50, as terminal performances were completely absent in Subject 3 and were present only to minor degrees in Subjects 1 and 5 at some of the lesser shock densities. Increases in rate occurred during the first few days after the change from the non-punishment to the punishment procedure; these increases also were of small magnitude and occurred under the less-frequent shock densities. Thus, on the first day of punishment training at the various density levels, increased rates occurred in seven of the nine density values in the range 6 to 18 min (median ratio = 0.54), while in the range 0.5 to 5.0 min, increases occurred in only one of nine values (median ratio = 0.43).

Although absolute non-punished baseline rates varied during the different phases of the experiment, non-punished rates did not vary systematically. Thus, the effects of punishment density summarized above in terms of relative rates primarily reflected changes in punished rates rather than baseline changes. Given below for each subject are the median and range of the non-punished baseline rates upon which the suppression ratios were based. Rates are in responses per minute. Subject 1: Median = 3.0, Range = 2.8-3.9; Subject 3: Median = 2.8, Range = 2.3-3.1; Subject 5: Median = 3.7, Range = 3.4-4.9.

Of interest is whether subjects minimized the numbers of shocks received during the avoidance and punishment phases. Figure 2 shows the terminal number of avoidable shocks received during the non-punished baseline phases (top panel) and the total numbers of avoidable and punishment shocks received at the end of training with each punishment density (bottom panel). Also shown is the minimum number of shocks available in each phase. During the baseline phases this number always was zero, because all shocks potentially could be avoided, while during the punishment periods the minimum depended on the particular density value. Because of the intervals of the avoidance schedule, *i.e.*, R-S:SS = 60:60 sec, the minimum number of shocks equaled the number of punishment shocks when densities were less than one shock each minute, whereas with densities exceeding one

Fig. 2. Shocks received during the baseline phases (top panel) and punishment phases (bottom panel) of Exp. I. Data were obtained during the last 60 min of the 90-min sessions. Each curve summarizes the terminal performances of a given animal at the various density values indicated on the abscissa. Note that density is expressed in terms of the duration of the intervals in which the first response was punished; reading from left to right, densities ranged from 120 shocks per hr (interval = 30 sec) to 5 shocks per hr (interval = 18 min). Also indicated are minimal numbers of shocks possible at each of the densities (see text). Delay of punishment was 20 sec for S1 and 40 sec for S3 and S5.

shock each minute the minimum number of shocks equaled the number of avoidance shocks. When the density was exactly one shock each minute, the minimum number of shocks was equal to either the potential number of punishment shocks or the potential number of avoidance shocks.

Comparisons of the extents to which subjects exceeded these minima indicated that Subject 5, punished with the 40-sec delay, was equally efficient under the baseline and punishment conditions; averaging over all density values, Subject 5 exceeded the minimum by 2.1 shocks/hr during the punishment phases and by 2.8 shocks/hr during the baseline phases. Subject 3, also punished with the 40-sec delay, was somewhat more efficient during the baseline condition than during the punishment condition, receiving 8.7 and 12.1 shocks/hr

respectively. Finally, Subject 1, trained with the 20-sec delay showed extreme reductions in efficiency in the range of densities from 3 to 18 min, receiving 24.2 excess shocks/hr in the punishment phases compared to the 6.0 shocks/hr received during the baseline phases. To be noted, however, in the case of Subject 1 at the 0.5-min density and all three subjects at the 1-min density, is that close to the minimum number of shocks were received.

EXPERIMENT II

Procedure

Four subjects were used. Subjects 1 and 5 had served in Exp. I; Subjects 2 and 4 had not been used previously. The procedures of Exp. II entailed holding punishment density constant at a given value and varying the extent of delay of punishment within the range 0 to 60 sec. The densities for Subjects 1 and 5, respectively, were one punishment each 6 min and one punishment each 4 min. Subject 2 was observed with density values of 3 and 18 min, and Subject 4 with density values of 1 and 9 min. Table 2 summarizes the delay and density values employed with each subject, the number of observations with each combination, and the order in which they were presented. To be noted in Table 2 is that two series were obtained for some of the density-delay combinations. In most instances, the duplicated observations were highly similar and the average of the two was used in the data analyses reported below. In the case of Subject 2, however, the first series of observations with density = 3 min and delay = 20 and 40 sec was markedly discrepant from the other data, and only the second series with these values is reported below.

RESULTS

As in Exp. I, relative rates were determined using performances during the last 60 min of the sessions. Figure 3 shows terminal ratios of punished to non-punished rates at the various values of delay and density. It is apparent that variations in delay and density of punishment produced orderly changes in behavior with suppression increasing in magnitude as delay was reduced and as density was increased. When the punishment density was once every 18 min, punishment had little or no influence even when delivered immediately after the punished response. By comparison, increases

Table 2

Number of sessions under each condition and the order in which the conditions were presented (parentheses) in Exp. II.

Delay	S1	S5	S4		S2	
	6-min Density	4-min Density	9-min Density	1-min Density	18-min Density	3-min Density
60 sec	7 (1)	12 (1)				
40 sec	8 (2)	9 (2)	17 (1) 17 (5)	20 (6)	34 (1) 10 (7)	6 (4) 15 (11)
20 sec		10 (3)		10 (7)	10 (8)	12 (5) 7 (12)
10 sec	8 (3)	4 (4)	10 (2)	2 (8)	9 (9)	15 (6) 7 (13)
5 sec	15 (4)		14 (3)		10 (2)	
0 sec	5 (5)		6 (4)		8 (3) 6 (10)

Fig. 3. Suppression ratios as a function of punishment delay and density in Exp. II. Rates during the punishment phases are expressed relative to prior non-punished rates (punished/non-punished + punished) with a ratio of 0.50 indicating no suppression and a ratio of 0.00 indicating complete suppression. Ratios are based on the last 60 min of the 90-min sessions. Each curve summarizes the terminal performances of a given animal at the various delay-density combinations indicated. Delay intervals ranged from 0 sec to 60 sec. Note that density is expressed in terms of the duration of the intervals in which the first response was punished. Densities ranged from 5 shocks per hr (interval = 18 min) to 60 shocks per hr (interval = 1 min). The point for S1 at density = 6 min, delay = 20 sec is based on data collected in Exp. I.

in density to once every 9 min and 6 min resulted in extreme suppression at the 0-sec value. At these greater density levels, the extent of suppression decreased as a negatively

accelerated function of increases in delay. Further increases in punishment density to either 4, 3, or 1 min produced virtually complete suppression at the 10-sec delay value. As density was increased among these last three values, the shape of the delay function changed progressively from one approximating a negatively accelerated function when frequency was 4 min, to a linear function at 3 min, and to a positively accelerated function at 1 min.

Figure 3 shows that increased rates in response to punishment were absent as a terminal reaction at any of the density or delay values studied in Exp. II. In addition, initial rate increases on the first days of punishment training were absent in Subject 1 (trained with the 1-min and 6-min densities) and Subject 5 (trained with the 4-min density), both of which had served in Exp. I. Small rate increases occurred, however, when Subject 2 was trained with the 18-min and 3-min densities (median ratios = 0.53 and 0.56 respectively), and when Subject 4 was trained with the 9-min density (median ratio = 0.52). Thus, the results suggest that extended punishment training (Subjects 1 and 5) eliminated any tendencies for increased rates, and that when increases occurred in other subjects, they were small, transient, and, as in Exp. I, associated with the lesser densities and longer delays of punishment.

Non-punished baseline rates in responses per minute are summarized below for the four subjects in Exp. II. As in Exp. I, non-punished rates, although not uniform through-

out, did not vary systematically during the different phases of the experiment. Subject 1: Median = 3.1, Range = 2.1-4.0; Subject 2: Median = 2.6, Range = 2.2-3.0; Subject 4: Median = 2.7, Range = 2.3-3.3; Subject 5: Median = 3.4, Range = 3.0-3.4.

The two panels of Fig. 4 show numbers of shocks received during the baseline and punishment phases. The right-hand ordinate of the bottom panel indicates the minimum number of shocks possible at each of the density levels studied. With respect to efficiency of performance in reaction to punishment, two features of the data in Fig. 4 are noteworthy. First, as was the case in Exp. I, behavior was most efficient at the 1-min density values, the value at which suppression was most extreme. Second, it is apparent that with the exception of the 1- and 18-min densities, where there was no apparent trend, the total number of shocks received varied as a function of the extent to which punishment was delayed, with subjects receiving increasing numbers of shocks as the delay interval was reduced. Since punishment density was the same at all points in each delay series, increases in total shocks resulted, primarily, from the increasing numbers of avoidable shocks that accompanied increasing suppression of avoidance behavior.

DISCUSSION

The central finding of the two experiments was that punishment suppressed ongoing avoidance responding under most conditions. The results showed, in addition, consistent effects associated with punishment density and delay, with the extent of suppression increasing as a function of increased density and decreased delay.

These results point to a number of similarities between the observed influences of punishment on ongoing avoidance and what is known about the influences of punishment on positively-reinforced baselines. The most fundamental similarity is that with both types of baselines, punishment suppresses ongoing responding. When positively reinforced baselines are involved, such suppression characteristically leads to a loss of positive reinforcement. By comparison, the present results indicated that suppression of avoidance by punishment usually resulted in increased

Fig. 4. Shocks received during the baseline phase (top panel) and punishment phases (bottom panel) of Exp. II. Data were obtained during the last 60 min of the 90-min sessions. Each curve summarizes the terminal performances of a given animal at the various delay-density combinations indicated. Delay intervals ranged from 0 sec to 60 sec. Note that density is expressed in terms of the duration of the intervals in which the first response was punished. Densities ranged from 5 shocks per hr (interval = 18 min) to 60 shocks per hr (interval = 1 min). The right-hand ordinate indicates the minimal number of shocks possible at each of the density values (see text).

numbers of avoidable shocks. A further similarity pertains to the influences of punishment delay. Gradients of punishment effectiveness similar to those of the present study have been observed when positively reinforced behavior is punished at varying delays in both free-operant (Camp, Raymond, and Church, 1967) and runway (Baron, 1965) situations. The present findings concerning the delay variable are similar also to results of a study by Kamin (1959) who observed a delay-of-punishment gradient when punishment was applied to an extinguishing avoidance response. Finally, the present finding that suppression increased as a function of increased punishment density bears some resemblance to the finding that when positively reinforced

behavior is punished according to a fixed-interval schedule, the degree of suppression increases as a function of decreases in the duration of the interval, and thus as a function of increases in the density of punishment (Appel, 1968).

Although punishment usually suppressed avoidance responding, under some conditions of the experiment punishment produced small rate increases. Such increases have been discussed by Sidman (1966), who suggested that heightened avoidance rates may occur when extra shocks are added to avoidance schedules because the extra shocks create spuriously shortened response-shock intervals and provide discriminative stimuli for responding. Heightened rates created in this way would not be expected to be maintained, however, because repeated exposure to the extra shocks permits the subject to discriminate that they are unavoidable. The present results are consistent with Sidman's analysis insofar as rate increases occurred most frequently as an initial reaction to punishment, and in those cases where the increases were maintained they were associated with the lesser punishment densities and longer punishment delays. Decreased density, by reducing the extent of exposure to the punishment shocks, would retard the development of the presumed discrimination; decreased delay would have the further consequence of reducing the discriminability of differences between avoidance and punishment shocks.

The results did not support the contention that when avoidance behavior is punished response rates are adopted which minimize the total number of shocks received (Sandler, *et al.* 1966). Instead, under most conditions of the experiment punishment had the opposite consequence of increasing numbers of shocks above the minimal levels dictated by the avoidance and punishment schedule. The extent of the excess was related to the particular values of density and delay that were involved, with excess shocks occurring most frequently when the density was less than one shock each minute (*i.e.*, in the range 3 to 18 min), and when the delay was short. These variations in the relative efficiency of performance in different phases of the experiments can be understood in terms of the suppressive effects of punishment and the influence of such suppression on relative rates of avoidance and punish-

ment shocks. When punishment density was in the range from 3 to 18 min, the mode of behavior minimizing total shocks was that of sustained avoidance behavior. As many as 60 shocks per hour could be received from the avoidance schedule (since R-S and S-S = 60 sec) while the above densities involved no more than 20 punishment shocks per hour (3 min) and as few as 3.3 shocks per hour (18 min). Thus, response suppression, while reducing the number of punishment shocks, had the consequence of increasing the occurrence of the more frequent avoidance shocks. By comparison, when the punishment density was either 1 min or 0.5 min, extreme response suppression effectively minimized total numbers of shock. This was because suppression at these densities, while resulting in most of the avoidance shocks, also precluded the occurrence of the punishment shocks, which were no more frequent than the avoidance shocks at the 1-min density (60 shocks per hour), and twice as frequent at the 0.5-min density.

That subjects did not, in general, minimize the total number of shocks argues against the hypothesis that when avoidance behavior is punished, response rates are controlled by the overall frequency of shocks. An alternative account suggested by the findings stresses that when avoidance behavior is punished, behavior comes under the control of the local consequences of responding. From this standpoint, responding had two outcomes in the present experiments: each response delayed the next avoidance shock by 60 sec and produced the punishment shock, usually at an interval shorter than 60 sec. It was this temporal difference between the response-shock and response-punishment intervals, presumably, that led to reductions in avoidance responding, even when such reductions resulted in increased overall shock frequencies.

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