FIXED-INTERVAL PUNISHMENT¹

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The average rate of bar-pressing maintained by a variable-interval schedule of milk reinforcement in 33 rats was found to be a decreasing function of intensity of concurrent punishment and, over a wide range of shock intensities, was inversely related to punishment frequency. Cumulative records were, however, negatively accelerated during 30-min punishment sessions with complete suppression occurring earlier and earlier (after fewer and fewer shocks) as intensity increased. In addition, acceleration was often observed between successive fixed-interval shock presentations and, at low and moderate intensities, bursts of responding occurred after each shock. The time to recover between punishment sessions (post-punishment recovery) was an increasing monotonic function of punishment intensity.

Although frequency and schedule of response-contingent aversive stimulation are known to be important determinants of the amount, pattern, and duration of suppression, the quantitative relationships between punishment frequency and other parameters have not yet been clearly delineated. Rate of bar-pressing maintained by variable-interval (VI) food reinforcement is, for example, a decreasing exponential function of the intensity of continuous punishment (Appel and Peterson, 1965), but the extent to which this kind of relationship also describes the effects of intermittent punishment remains to be established. In the present experiment, the effects of several frequencies of fixed-interval (FI) punishment were analyzed over a wide range of shock intensities.

METHOD

Subjects

Thirty-three male albino rats of Sprague-Dawley strain were obtained from the Charles River Breeding Laboratories, Wilmington, Massachusetts. All were experimentally naive and were 90 days old at the beginning of the investigation. They were maintained on a 22-hr food deprivation schedule in a climate-

controlled room (75° F) kept on a 12-hr day-night cycle.

Apparatus

Two light-shielded and sound-insulated boxes were built so that their inside dimensions (9 in. by 8 in. by 9 in.) were identical to those described in previous experiments (Appel, 1963; Appel and Peterson, 1965; Filby and Appel, 1966). Each box was dimly illuminated by a 28-v bulb behind a white translucent panel directly above a single bar that was activated by a force of approximately 15 g. A dipper feeder (R. Gerbrands Co.), which delivered 0.05 ml of sweetened milk and vitamins, was located to the right of the bar; shock from a Grason-Stadler model 1064 GS generator and scrambler was delivered through the bar, the front and rear walls of the box, and the grid floor.

To control for possible differences between the two boxes, about half of each group was assigned to each box. The grids and adjacent walls of the boxes were thoroughly cleaned daily to maintain constant resistance from day to day. Scheduling and recording equipment were housed in an adjacent room.

Procedure

All animals were tested at the same time each day, seven days per week for a period of several months. They were acclimated to the box and trained to press the bar on a continuous reinforcement (CRF) schedule during a single 30-min session. Frequency of rein-

¹This research was supported by Grant NSF-GB-5933, from the National Science Foundation. Reprints may be obtained from: J. B. Appel, Department of Psychiatry, The University of Chicago, 950 East 59th Street, Chicago, Illinois 60637.

forcement was then gradually decreased until a VI 1-min schedule was in effect; each animal was allowed at least two weeks for its rate to stabilize.

The animals were then randomly divided into five groups on the basis of frequency of concurrent FI punishment. A continuous punishment (CP) group ($N = 7$) was to be given a response-contingent shock of 0.5-sec duration after every response during punishment sessions. In practice, the scheduling timer limited the punishment to a frequency of about FI 1- to 2-sec. An FI 10-sec group ($N = 6$) received concurrent punishment for the first response after 10 sec elapsed. The remaining groups were FI 0.5-min ($N = 7$), FI 1-min ($N = 6$), and FI 2-min ($N = 7$). The N s were unequal because some animals had to be discarded due to illness or apparatus failure.

Each animal was given a single 30-min

session of exposure to each shock intensity (0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8 ma) in an ascending order; amount of suppression obtained at each intensity was therefore minimal (Appel and Peterson, 1965). Sessions of concurrent VI reinforcement and FI punishment were always separated by several days of VI (no punishment) to allow rates of bar-pressing to return to baseline (100% of pre-shock rate for one session) and between-session (post-punishment) recovery to be measured.

RESULTS

Figure 1 shows that rate of concurrently punished responding is a decreasing monotonic function of shock intensity at all punishment frequencies. The rate during each 30-min punishment session was expressed as a percentage of the VI rate during the two ses-

Fig. 1. Average rates of bar-pressing on a concurrent VI 1-min FI pun schedule at five punishment frequencies as functions of shock intensity.

Table 1

Mean Response Rates, Standard Deviations and Results of Statistical Analyses

		Shock Intensity (ma)							
		0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.8
CP	$\bar{X}$	105	62	30	1	0	0	0	0
N = 7	S.D.	22	42	24	2	0	0	0	0
FI 10-sec	$\bar{X}$	104	98	33	9	3	0	0	0
N = 6	S.D.	20	15	27	13	7	0	0	0
FI 0.5-min	$\bar{X}$	101	126	68	37	7	1	0	0
N = 7	S.D.	17	31	26	46	12	1	0	0
FI 1-min	$\bar{X}$	117	103	88	38	35	4	2	0
N = 6	S.D.	28	16	16	24	54	7	2	0
FI 2-min	$\bar{X}$	98	95	93	71	44	26	16	9
N = 7	S.D.	22	28	32	36	36	23	13	9
$x^2r =$		4.15	10.05	17.93	13.98	12.10	11.84	14.76	6.11
p		NS	<0.05	<0.01	<0.01	<0.05	<0.05	<0.01	NS

sions preceding each intensity for each animal and group averages were computed from these data; these means are plotted in the figure.

The shape of each curve is approximately exponential but a large variance at each point (Table 1), presumably due to differential sensitivity to grid-shock among animals, limits both the strength of this inference and the utility of parametric statistical analyses. A non-parametric rank test (Wilcoxon, 1949) was therefore used to test the differences in amount of suppression among the groups at each punishment intensity. This analysis showed that the groups differed significantly at intermediate punishment intensities, *i.e.*, 0.1 to 0.6 ma (Table 1). The lowest intensity (0.05 ma) induced no suppression and the highest intensity (0.8 ma) induced complete suppression in four of the five groups.

In spite of the large variance, a number of conclusions can be drawn about the performances of individual animals under punishment. First, Fig. 2 shows that, in general, the average rate during punishment is a decreasing monotonic function of intensity for each subject as well as for the group. That is, suppression is not an all or none phenomenon and the average curves of Fig. 1 do not result from different rats suppressing completely or not at all at different intensities. While Fig. 2 shows only two punishment frequencies (FI 1-min and FI 2-min), similar results were obtained at CP, FI 10-sec, and FI 0.5-min.

The pattern of responding under punishment is shown for one animal (Rat No. 146) at

one frequency (FI 2-min) in the cumulative records of Fig. 3, but it can be taken as typical of all subjects. A stable rate of VI responding during the final session before punishment (at 0.05 ma) is shown at the upper left. As intensity of punishment increases (shown in the remaining curves of the figure), the overall

Fig. 2. Average and individual performances of the FI 1-min and FI 2-min punishment groups at all shock intensities.

rate not only decreases, but becomes more and more negatively accelerated. Within-session recovery (adaptation) does not occur during relatively short (30-min) sessions even at low intensities (Fig. 3, 0.05 ma). Moreover, complete suppression, which can eventually be observed during all sessions of an intensity of at least 0.4 ma, if not at 0.3 ma, begins earlier and earlier as intensity increases, *i.e.*, fewer and fewer shocks are needed to eliminate behavior.

Changes in local rate of bar-pressing are correlated with both the administration and intensity of shock. In general, the rate is negatively accelerated; the animal slows down

as the time for punishment (indicated by dots) approaches and speeds up (bursts) as soon as each punishment at low or moderate intensities occurs. At higher intensities, however, the animal stops responding after a few shocks.

The effects of intermittent, fixed-interval punishment often last after punishment has been withdrawn. Figure 4 shows the number of sessions required for the rate of VI (non-punished) responding to return to normal (100% of pre-punishment rate) after exposure to each punishment intensity. Post-punishment recovery is an increasing monotonic function of intensity (Fig. 4) but, surprisingly, is unrelated to frequency (Table insert, Fig. 4).

Fig. 3. Cumulative records of the performance of a single animal during the last session before (0.05-ma) punishment (control) and sessions of concurrent VI 1-min FI 2-min Pun. Shocks are indicated by dots and reinforcements, by vertical "pips".

Fig. 4. Recovery Time, defined as the number of days to return to 100% of baseline (VI) rate after exposure to punishment at intensities shown on the abscissa. The graph shows the average performance pooled over all groups; the table gives group scores.

DISCUSSION

That the rate of punished responding during intermittent (FI) punishment during relatively short experimental sessions is a decreasing monotonic (and probably exponential) function of intensity confirms and extends earlier findings concerning continuous punishment in the rat (Appel and Peterson, 1965) and pigeon (Azrin and Holz, 1966). Decreasing the frequency reduces the suppressing effects of response-contingent shock over a wide but limited range of intensities, *e.g.*, this variable is of little if any importance under the conditions of this study if punishment intensity exceeds 1.0 ma. It can be reasonably hypothesized, however, that frequency, like duration (Church, Raymond, and Beauchamp, 1967), interacts with intensity in a linear manner to determine the "aversiveness" of shock; amount

of suppression may then be assumed to be exponentially related to this intervening variable.

The overall pattern of intra-session responding under FI punishment in the rat (*i.e.*, negative acceleration) indicates that little recovery or adaptation occurs during relatively short experimental sessions when relatively few shocks are administered. This result does not necessarily mean that adaptation would not occur in longer sessions. Indeed, the fact that moderate intensities of continuous punishment and longer sessions of intermittent punishment seem to be associated with positively accelerated rates of punished responding (Azrin, 1959) suggest that recovery is related to amount of exposure to shock in the presence of concurrent reinforcement. Shock must, in other words, be sufficiently paired with reinforcement before its "aversive" properties can

be at least partially overcome (Holz and Azrin, 1961; Appel, 1968).

That negative acceleration also occurs between shock presentations confirms previous findings on the effects of FI punishment (Hunt and Brady, 1955; Azrin, 1956). The burst or accelerated rate after shock may be an unconditioned "emotional" response to shock (Sidman, 1958) but the "burst" might also reflect the fact that the occurrence of punishment may become a discriminative stimulus for the non-occurrence of further punishment on an FI schedule so that bar-pressing is therefore "safe". Such a discriminative function is obscured by the increased "aversiveness" of the shock at higher intensities (Holz and Azrin, 1961).

The return of punished behavior to its normal rate of occurrence, once punishment has been withdrawn, has been related to both intensity (Filby and Appel, 1966) and frequency (Estes, 1944) of punishment. Why frequency of punishment does not determine rate of recovery in the present experiment is not clear. With repeated sessions of exposure to continuous punishment, even at relatively high intensities, both rats and pigeons return to baseline as soon as punishment is withdrawn (Appel and Peterson, 1965) or may even "overshoot" normal levels (Azrin, 1960). Perhaps with fewer and shorter sessions of concurrent, intermittent shock and intermittent reinforcement the animal has difficulty learning to discriminate between shock and no-shock (VI) conditions, particularly after exposure to high intensities when few responses occur. In any event, shock intensity, as well as the manner in which an animal is introduced to punishment, (Hake, Azrin, and Oxford, 1967) probably determines the rate of post-punishment recovery as well as the amount of initial suppression.

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Received 8 April 1968.