FIXED-RATIO PUNISHMENT WITH CONTINUOUS REINFORCEMENT¹

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Rats were reinforced with water for every bar-press and concurrently punished for every 10th or 20th bar-press. Punishment produced an initial suppression of responding followed by recovery. A slight change in the method of delivering punishment eventually led to a high response rate just after punishment, a low response rate just before punishment, and frequent intermediate pauses. The results are interpreted as showing that punishment became a safe signal and that the high rate of responding it released came to act as a conditioned aversive stimulus. The effects of amphetamine were consistent with this interpretation. Alcohol had the paradoxical effect of increasing pauses and depressing the low rate before punishment.

Azrin (1956) first suggested that the delivery of aversive stimuli according to different schedules might produce typical patterns of responding related to those produced by the corresponding schedules of reinforcement. He maintained responding on a variable-interval schedule of reinforcement (VI reinf) and introduced signaled periods in which punishment was also scheduled. The complete schedule, in the case of fixed-interval punishment (FI pun), could be represented as Mult [VI reinf; Con (VI reinf, FI pun)]. Azrin interpreted the relative changes in response rate during "dangerous" periods as supporting the general view that punishment has the opposite effect from reinforcement. With FI pun, for example, rate was negatively accelerated.

With fixed-ratio punishment, response rate might also be expected to decline as the number of unpunished responses increased. This result was not obtained by Azrin, Holz, and Hake (1963), using concurrent VI reinf and FR pun. They found a uniform depressant effect of punishment on response rate, and only rare instances of a differentiated pattern of responding between punishments. However, VI reinf differentially reinforces low rates. Consequently, the reinforcement schedule would counteract any tendency of the punishment schedule to produce high rates. This consideration is less relevant to Azrin's original study of response-correlated shock, in

which periods of punishment were explicitly signaled and punishments could be avoided at very small cost in reinforcements. It was because of such possible interaction that we chose continuous reinforcement (CRF), which does not differentially reinforce rate, as the concurrent reinforcement schedule with FR pun.

METHOD

Subjects

Eight male albino rats, about 3 months old at the beginning of the experiment, served.

Apparatus

Three identical operant conditioning boxes, with control and recording equipment located in an adjacent room were used. The boxes measured 8 in. by 9 in. by 10 in. high, with aluminum walls and a clear plastic top. The floor was a grid consisting of seven alloy rods, $\frac{5}{8}$ in. in diameter, mounted on $1\frac{1}{8}$ in. centers, running the length of the box. A bar, operated by a force of 30 g, projected from one (narrow) wall, 3 in. above the floor. A small drinking well was located just below and to one side of the bar. Electric shock from the secondary of a power transformer could be applied either to alternate rods of the grid ("grid-shock") or between the entire grid and the bar ("bar-shock"). Thus, grid shock was to the hind paws, and bar shock was between fore paws and hind paws. Shock intensity was controlled by a potentiometer and limited by a 220 K

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Fig. 1. Typical initial effect of fixed-ratio punishment (300 v), and later recovery; S5 on the left, S4 on the right. Every response was reinforced and pips indicate punished responses. Session numbers are circled; -1 indicates the pre-punishment session. Punishment was omitted on session 42.

ohm series resistor. Shock duration was about 50 msec. Each box had a water pump, which operated with slight vibration and noise. Consequently, distinctive exteroceptive feedback was normally provided for every response.

Procedure

Two of the subjects (S7 and S8) were exposed only to continuous reinforcement (CRF), limited to 200 reinforcements per session. Most of the results were obtained from the other six Ss (S1 to S6), which received both CRF and

fixed-ratio punishment. They were trained to bar-press for water and given 200 reinforcements in one session, before the administration of punishment. The amount of water per reinforcement was 0.03 ml. Reinforcements, up to the capacity of the drinking well (about 0.1 ml.), remained available until consumed. Subjects were given water *ad lib* for 15 min shortly after each daily session, which generally lasted 1 hr.

Punishment (300 v grid-shock—*i.e.* no shock on the bar) was given on every 20th response

Fig. 2. Cumulative record segments selected to show differentiation of response rate between punishments (pips). Reading from left to right, the records were produced by S6 (400 v), S5 (350 v), S4, S1, S2, S3 (all 300 v).

Fig. 3. Short-term effect of increasing punishment intensity. The upper trace shows performance with a punishment intensity of 300 v. The lower trace shows performance on the next session with a punishment intensity of 500 v. Pips indicate punished responses.

(FR 20). The shock went on the instant the microswitch of the bar operated. After 18 sessions, the schedule was changed to FR 10 for three Ss. After performance had stabilized, punishment was omitted for one session. Bar-shock was then substituted for grid-shock for the remainder of the experiment—some 100 sessions. During these sessions the intensity of punishment was changed from time to time. The effects of *dl*-amphetamine sulfate and ethyl alcohol on the performance of all eight Ss were studied. The experimental animals were given i/p injections immediately before a session. Test sessions with drugs were separated by a number of sessions with injections of the vehicle (physiological saline or distilled water). Drugs were not administered unless performance had returned to the pre-drug baseline on the preceding (control) session. The amphetamine doses were 1.0, 2.0 and 3.0 mg/kg. The alcohol doses were 0.5, 1.0, 1.5 and 2.0 mg/g. The weight of all injections was 1% of the animal's body weight. The effect of drinking 8 ml water immediately before a session was also determined.

RESULTS

Grid-Shock

The first few shocks suppressed bar-pressing, followed by a gradual recovery which was complete after about 15 sessions. During recovery,

punishment was followed by long pauses and positively accelerated responding. At a later stage, when pauses occurred, they tended not to appear immediately after shock. Eventually the rate of responding seemed to be little affected by punishment. The fully recovered response rate was about the same as it had been during the session of CRF and the only effect of omission of punishment was a greater persistence of responding towards the end of the session. All these effects are illustrated in Fig. 1. No effect could be detected of the change to FR 10, which occurred after complete recovery of bar-pressing.

Fig. 4. S6. Short-term effect of increasing punishment intensity in successive sessions. A: Punishment intensity 300 v. B: Punishment intensity 500 v. Pips indicate punished responses.

Fig. 5. Short-term vs long-term effects of increasing punishment intensity; S1 on the left, S4 on the right. Pips indicate punished responses. Session numbers are circled. They represent the number of bar-shock sessions, not the number of sessions since the beginning of the experiment. The punishment intensity was 300 v on session 13 and 400 v on sessions 14 through 16. S1 shows a partial recovery of original performance at the lower intensity; S4 shows a progressive decline in performance.

Fig. 6. The effect of amphetamine on fixed-ratio punishment (FR 10). Performance after: A, saline i/p; B, 1.0 mg/kg amphetamine i/p; C, 3.0 mg/kg amphetamine i/p. Pips indicate punished responses. S3 was replaced in his home cage for 90 min between the two records shown as "A" and "A and 90 min." Numbers indicate the length in minutes of a portion of the record extracted at the break. Punishment intensity was 150 v for S1 (top), 300 v for S2 (middle) and 400 v for S3 (bottom).

Bar-Shock

The change to bar-shock produced a gradual and irregular decline and partial recovery in rate of bar-pressing, requiring 6 to 30 sessions depending on the S. The rate of bar-pressing even after recovery was usually lower than with grid-shock. In addition, performance showed slow drifts throughout the rest of the experiment.

Differentiated response rates between punishments emerged with bar-shock. The basic pattern was a high rate immediately after punishment, followed by a low rate, sometimes accelerating, up to the next punishment. The two rates were often separated by relatively long pauses or very low rates, as shown in Fig. 2. The records shown in Fig. 2 were selected to show differentiation, since it was not

Fig. 7. The effect of amphetamine on fixed-ratio punishment (FR 20). Punishment intensity was 200 v for S4 (top), 350 v for S5 (middle), and 400 v for S6 (bottom). See Fig. 6.

always present. An upward drift in response rates was usually accompanied by disappearance of the lower rate just before punishment. A downward drift in response rates was accompanied by more frequent pausing and attenuation of the high rate just after punishment. To maintain differentiation, the intensity of punishment was raised or lowered whenever the response rate was seen to have drifted upwards or downwards in the previous few sessions. Because of this procedure, few systematic data were obtained on the effects of punishment intensity. In view of the relative instability of performance, any attempt to relate a fixed level of performance to a given punishment intensity would be misleading. However, changes in punishment intensity did produce changes in performance. Figure 3 shows that, except for the doubtful case of S4, the overall response rate is lowered by an increase in the punishment intensity from 300 v to 500 v.

If the response rate was high, so that differentiation was weak, an increase in punishment intensity usually increased differentiation. This is illustrated in Fig. 4.

Fig. 8. The effects of alcohol and satiation on fixed-ratio punishment (FR 10). Performance after: A, distilled water i/p; B, 0.5 mg/g alcohol i/p; C, 2.0 mg/g alcohol i/p; D, drinking 8 ml of water immediately before the session. Pips indicate punished responses. Numbers indicate the same as in Fig. 6. Records are from S1, S2, and S3, reading from left to right. Punishment intensities are the same as in Fig. 6.

The initial effect of a change in intensity might not be maintained in subsequent sessions. Figure 5 shows examples of opposite effects after the initial lowering of response rate by an increase in punishment intensity. In one case the rate continues to decline; in the other it partially recovers.

Effects of alcohol and amphetamine

Figures 6 to 9 show the drug effects for individual experimental Ss. Mean and median IRTs of all Ss are compared in Fig. 10 and Fig. 11. It can be seen that the drug effects on the performance of S7 and S8 are small in comparison with their effects on S1–S6. Figure 10 shows that pre-watering, alcohol and amphetamine increase the mean IRT of S1–S6. Figure 11 shows that amphetamine is the only agent which increases median IRT. Therefore, alcohol and pre-watering reduced the overall rate of responding by increasing the length, not the proportion, of long IRTs. Amphetamine, on the other hand, increased the proportion of long IRTs, as well, perhaps, as their length.

Figure 12 shows the effects of the drugs and pre-watering in detail in the case of S1 and S6. It can be seen in Fig. 12 that amphetamine reduces the number of rapid responses emitted just after punishment. In the case of S1, the rapid responding is eliminated. Alcohol and pre-watering, on the other hand, have little effect on the high rate after punishment. They appear mainly to increase pausing and reduce the low rate just before punishment. These effects may also be seen in Fig. 6 to 9.

DISCUSSION

The introduction of punishment had the same effect as that found by Azrin *et al.* (1963). Initial suppression was followed by the temporary appearance of accelerated responding between punishments. We obtained complete recovery of initial response rate with the moderate intensity of punishment used, whereas Azrin *et al.*, obtained complete recovery only at the lowest intensity of punishment.

The possibility was considered that the complete recovery of bar-pressing with grid-shock

was due to the Ss learning to avoid most of the shocks. This was extremely unlikely in view of the design of the grid. Shock-avoidance by standing on one rod or two rods of the same polarity is very rare when the rods run at right angles to the wall containing the bar. The shock produced a distinct twitch in all subjects. Frequent observation showed that this sign of punishment was still present even when no effect on response rate could be detected.

It is certain that systematic avoidance was not learned by any S, but it is not certain that every scheduled grid shock was received. This was the reason for changing to bar-shock, which would require very unusual circumstances to prevent the delivery of shock. Avoidance behavior such as operating the bar with a furry part of the body was looked for but never observed.

It was observed that the general bodily twitch produced by shock was accompanied by a recoil from the bar in the case of bar-shock, but not in the case of grid-shock. The recoil followed every actual and abortive bar-press for many sessions in the case of some Ss,

being simply more vigorous when shock was actually delivered. These observations are relevant to an "interference" theory of the effect of punishment. According to this view, responses elicited by punishment are learned and compete with the punished response. Strong support for this view was obtained by Fowler and Miller (1963). They showed that a weak shock at the goal increased or decreased runway speed according to whether the shock was applied to the hind paws (eliciting forward motion) or the fore paws (eliciting backward motion). This result is similar to that obtained in the present experiment. The effect of the bar-shock (recoil from the bar) was clearly incompatible with bar-pressing; but the effect of grid-shock was not. Consequently, bar-shock was a more effective deterrent than the same intensity grid-shock.

The main result of this experiment is the considerable amount of differentiated responding between punishments. Differences in this respect between the present results and those of Azrin *et al.* (1963) might be due to several factors. We have already suggested that the effects of differential reinforcement of rates

Fig. 9. The effects of alcohol and satiation on fixed-ratio punishment (FR 20). Records are from S4, S5, and S6, reading from left to right. Punishment intensities are the same as in Fig. 7. See Fig. 8.

(by a VI schedule) might conceal the effects of differential punishment of rates. Another possibility is that the crucial difference is in the absolute rates of reinforcement or punishment. In both respects the two studies differ by an order of magnitude.

The present results show that FR pun does produce a recognizable pattern of behavior, with perhaps more individual variation than in the case of FR reinf. However, the pattern of behavior produced by FR pun is not related in a simple way to that produced by FR reinf. The assumption that FR pun would have the "opposite" effect from FR reinf was not confirmed.

Punishment came to act as a cue controlling a relatively high probability of response. Since all responses were reinforced, the punishment did not act as a discriminative stimulus in its usual sense of a signal for "not-extinction". However, every punishment initiated a period of unpunished responding. A punishment was therefore a discriminative stimulus in the novel sense of a signal for "no punishment". Such a stimulus may be called a "safe signal".

Fig. 10. Means of the first 100 IRTs in a session as a function of pre-watering 8 ml (PW), alcohol, and amphetamine. Control measures (C) were obtained from Control sessions interspersed with the drug sessions. The ordinate is logarithmic.

Fig. 11. Median IRTs calculated from the same sessions as those used in Fig. 10. The ordinate is linear. The mean median IRT of S1-S6 was at least 9 sec with the higher doses of amphetamine, but the recording apparatus was unable to resolve durations greater than 8 sec.

Whether a safe signal has all the properties of an S^D is an open question.

The low rate just before punishment may be regarded as a case of depression of positively reinforced responses by cues which signify that further responses may be punished (Hunt and Brady, 1955). Thus, in general, rapid responding gave way to slower responding. When the two response rates could be clearly distinguished, the pattern of responding was obviously similar whether the punishment schedule was FR 10 or FR 20. Since no punishment-correlated cues independent of the S_s' behavior were provided, this result indicates that response-produced cues mediated the control attributable to the punishment schedule.

We interpret the results, therefore, as showing that FR punishments came to act as safe signals, releasing relatively rapid trains of responses mainly under the control of the reinforcement schedule. These responses produced conditioned aversive stimuli which in turn depressed the initial high rate.

Fig. 12. Detailed comparison of the effects of moderate doses of amphetamine and alcohol, and pre-watering. Traces on the left were produced by S1. Traces on the right were produced by S6.

A, Typical control performance.
B, Performance after 2 mg/kg amphetamine.
C, Performance after 15 mg/g alcohol.

D, Performance after drinking 8 ml water before the session. Pips indicate punished responses. All records are of performance 30 min after the beginning of the session.

The effects of amphetamine are consistent with this analysis. Amphetamine is known to depress responding during pre-aversive stimuli (Brady, 1956). In addition, amphetamine reduces the rate of responding when responses are both punished and reinforced (Geller and Seifter, 1960). In short, amphetamine enhances the effectiveness of aversive influences on reinforced behavior. In the present experiment the high doses of amphetamine produced prolonged suppression of responding on the concurrent schedule, but not on CRF. Under amphetamine, the train of rapid responses after punishment was shorter; *i.e.*, the transition from a high to a low rate, being due to a competing aversive influence, was facilitated by amphetamine.

Behavior suppressed by conditioned aversive stimuli often recovers when the animal is given alcohol (Conger, 1951; Masserman and Yum, 1946; Miller and Barry, 1960). Alcohol was therefore expected to alleviate the depres-

sion of responding just before punishment. The effect was just the opposite—an enhancement of the depression of responding before punishment. The effects of alcohol were similar to those of pre-watering. The possibility that alcohol reduces the strength of all responses motivated by water deprivation cannot be dismissed. Such an interpretation is implausible, however, since alcohol is a dehydrating agent. In addition, the results of the control Ss show that such an effect, if it exists, is not strong enough to affect performance on CRF.

The effects of alcohol do not fit in well with the present analysis. They are, however, interesting in their own right, since they go counter to previous results, which have shown an attenuation of the effects of aversive stimuli after administration of alcohol (*cf.* Miller and Barry, 1960).

REFERENCES

- Azrin, N. H. Some effects of two intermittent schedules of immediate and non-immediate punishment. *J. Psychol.*, 1956, **42**, 3-21.
- Azrin, N. H., Holz, W. C., and Hake, D. F. Fixed-ratio punishment. *J. exp. Anal. Behav.*, 1963, **6**, 141-148.
- Brady, J. V. A comparative approach to the evaluation of drug effects upon affective behavior. *Ann. N.Y. Acad. Sci.*, 1956, **64**, 632-643.
- Conger, J. J. The effects of alcohol on conflict behavior in the albino rat. *Quart. J. Stud. Alcohol*, 1951, **12**, 1-29.
- Fowler, H. and Miller, N. E. Facilitation and inhibition of runway performance by hind- and forepaw shock of various intensities. *J. comp. physiol. Psychol.*, 1963, **56**, 801-805.
- Geller, I. and Seifter, J. The effects of meprobamate, barbiturates, d-amphetamine and promazine on experimentally induced conflict in the rat. *Psychopharmacologia*, 1960, **1**, 482-492.
- Hunt, H. F. and Brady, J. V. Some effects of punishment and intercurrent "anxiety" on a simple operant. *J. comp. physiol. Psychol.*, 1955, **48**, 305-310.
- Masserman, J. H. and Yum, K. S. An analysis of the influence of alcohol on experimental neurosis in cats. *Psychosom. Med.*, 1946, **8**, 36-52.
- Miller, N. E. and Barry, Herbert III. Motivational effects of drugs: methods which illustrate some general problems in psychopharmacology. *Psychopharmacologia*, 1960, **1**, 169-199.

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