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PUNISHMENT AND RATE OF POSITIVE REINFORCEMENT[1]

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This experiment investigated the effect of several punishment intensities on two responses maintained by contrasting rates of reinforcement. The responses were concurrently reinforced according to two different variable-interval schedules. Because these schedules were independent of one another and programmed different rates of reinforcement, the two responses occurred at dissimilar rates. When responses were simultaneously suppressed by punishment, both rates were reduced proportionately until suppression was virtually complete. In other words, the per cent suppression resulting from punishment was independent of the rate at which the response was reinforced. Phenomena found in single-response studies were duplicated here. Responding tended to increase both within and between punishment sessions at mild and moderate punishment intensities. Cessation of punishment led to a "compensatory" overshooting beyond the prepunished response rate.

The rate at which a response is reinforced might be expected to influence its susceptibility to punishment. Church (1963) and Solomon (1964) reviewed a variety of experimental findings that suggest punishment reduces weak responses more than strong ones. Since response strength is generally considered to be a positive function of reinforcement rate, punishment would be expected to have less effect as reinforcement rate increases.

One experiment (Church and Raymond, 1967), which directly studied the relationship, supports this view. A lever-press response was reinforced with food according to either a 5-min or 0.2-min variable-interval schedule with two groups of rats. The response for both groups was then punished with electric shock on a 2-min variable-interval schedule. Greater reduction occurred with the response that was reinforced less often.

The present experiment studied the relationship with individual subjects that emitted two responses during the same experimental periods. The responses were maintained by two different variable-interval schedules of reinforcement programmed concurrently. Such concurrent schedules have been shown to produce rates of response that are proportionate to the rates of reinforcement (Herrnstein, 1961; Catania, 1966). A change in the rate of reinforcement for the two responses produces a corresponding change in rates of response. When the variable-interval schedules are studied separately, the proportionate relationship is not present. In this respect, responses maintained by concurrent schedules are more sensitive to rate of reinforcement. Other experiments, such as those concerned with magnitude of reinforcement (Catania, 1963; Neuringer, 1967), suggest that the concurrent responses are also especially sensitive to the effects of other independent variables.

METHOD

Subjects

Two male White Carneaux pigeons were maintained at 80% of free-feeding weights. Both were experimentally naive at the beginning of the experiment.

Apparatus

The experimental space was 11 by 10 by 11 in. high, located within a sound attenuating compartment. Two response keys, 1 in. in diameter, 2.75 in. apart, and 7.5 in. above the floor, were activated by pecks with a force of at least 12 g. Each key was transilluminated with a different colored light (green left, yel-

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low right), and all pecks on the keys produced a distinctive click as "feedback". Reinforcement consisted of a 3.5-sec exposure of a grain magazine located below and midway between the two response keys.

Electric shock was the punishing stimulus. The shock source was 115 v, 60 cycles, ac, which was dropped through series resistors to provide nominal currents of 3, 6, 7.5, 9, or 12 ma (actual current flow measured with 1000-ohm resistor in place of the subject was 3.1, 5.9, 7.2, 9.0, 11.5 ma). The electric shock was delivered through gold electrodes, implanted around the subject's pubis bones (Azrin, 1959*a*). When shocks were scheduled, responding on both keys was punished with the same intensity and duration. Shock duration was 90 msec, with variability less than 2%. To assure the equivalence of the shock for the two keys, the critical elements of the two shock circuits were reversed during several punishment sessions. This had no effect on responding.

Procedure

After the subjects had been trained to peck both keys, reinforcement was intermittently scheduled according to two variable-interval schedules (*conc* VI, VI). The mean interreinforcement interval of the VI's was increased until a 3-min average was reached on each key. A changeover delay (a period during which responses would not deliver programmed reinforcements immediately after a change from one key to the other) of 0.65 sec after the first response on the new key was also in effect throughout the experiment. Daily sessions lasted for 2 hr or until 50 reinforcements had been delivered, whichever came first.

Several concurrent variable-interval schedules with different mean values were employed for brief periods. These schedules, *conc* VI 3-min, VI 3-min; *conc* VI 1.6-min, VI 30-sec; *conc* VI 7.5-min, VI 1.9-min (nominal values) were used to assure that responding was sensitive to differences in reinforcement rates. In all cases after brief stabilization the proportion of the rates on the two keys was within 10% of the proportion of reinforcements delivered.

After this preliminary training, responding was reinforced according to VI 1.9-min (measured value 1.5) on the left key and VI 7.5-min (measured value 7.0) on the right key. This schedule was used for the remainder of the experiment while responding was suppressed by punishment. It scheduled reinforcements roughly in the proportion of 4:1 on the two keys. This proportion was chosen because it was sufficiently large to produce clearly different rates of response. Yet, the proportion was not so large that the low rate would be too low to detect reliably a further decrease. The subjects remained on this schedule for 90 sessions before punishment was introduced.

Next, every peck on both keys was punished. A series of progressively increasing punishment intensities was used: 3, 6, 7.5, 9, and 12 ma, and the performance was allowed to stabilize with each intensity before the next was introduced. This sequence was completed in approximately 90 sessions, and provided several degrees of response suppression ranging from slight to complete. Punishment was then removed and the unpunished rate was again observed. After this major portion of the experiment, the effect of a briefer period of 3-ma punishment was observed.

RESULTS

Figure 1 shows the effect of punishment intensity on the two responses. In the upper portion, rate of response is plotted. Before punishment was introduced, the *conc* VI 1.9-min, VI 7.5-min schedule maintained responding on the two keys at rates of 67 and 18 responses per min for subject B#326 and at rates of 92 and 30 per min for B#327. Each point in Fig. 1 represents the mean rates at each intensity after performance stabilized. These means were determined by dividing the number of responses on each key by the session duration and averaging over sessions. When response rate was plotted against a logarithmic abscissa of shock intensity, the suppression was roughly linear. A line fitted by the method of least squares is shown in the figure.

The lower portion of Fig. 1 shows the same data expressed as a per cent of the nonpunished rates. In this case, the points virtually coincide. Thus, Fig. 1 shows that although the punishment had a greater absolute effect on the response maintained by the higher frequency of reinforcement, the response rates were always reduced proportionally.

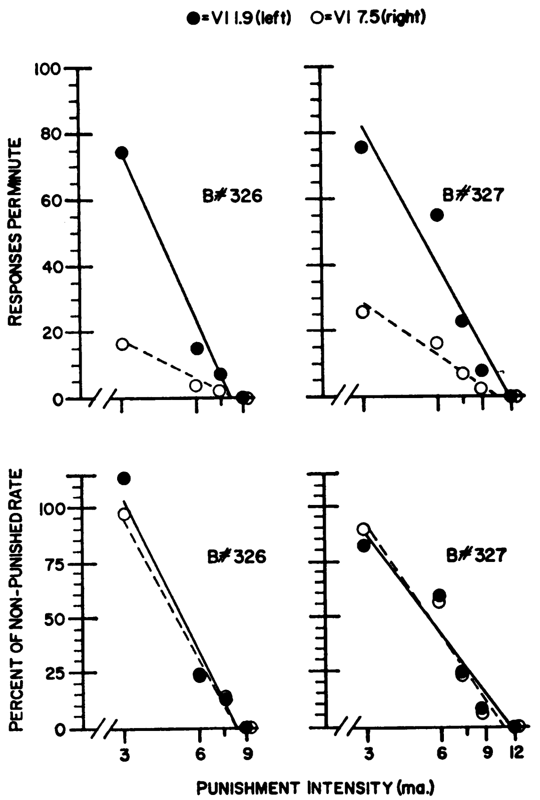

Fig. 1. The effect of punishment on *conc* VI 1.9-min, VI 7.5-min. Upper portion indicates the changes in the two response rates as a function of punishment intensity. Lower portion indicates these same changes expressed as a percentage of the prepunishment rate.

Another way of looking at the consistency of this relative suppression is to consider the proportion of the total responses emitted on a particular key at each level of punishment. This proportion will be invariant if both responses are reduced comparatively. Table 1 shows for each shock intensity the mean proportion of responses on the key associated with the lower rate of reinforcement. The 95% confidence limits of the difference between the punishment values and the no-punishment values appear in the column to the far right. Inspection of the confidence limits reveals that 0 is covered in every instance and so none of the differences reach statistical significance. Furthermore, the narrow range of each set of limits indicates little deviation from the mean values.

With variable-interval reinforcement schedules, response rates can change considerably without affecting reinforcement rate. As long as responses are emitted steadily, above a minimum rate, reinforcements will be produced nearly as soon as the schedule programs them. However, if long pauses in responding should result during punishment, reinforcement rate would be reduced. Such a lowered reinforcement rate might then in turn interact with punishment's effect. Table 2 shows the actual rates of reinforcement at each punishment intensity. These rates were little changed by punishment. Even at the highest intensity the reduction in reinforcement rate was slight and proportional for both responses.

The third column shows the difference between the proportion of responses emitted on the right key and the proportion of reinforcements obtained by responses there. If response rate had exactly matched reinforcement rate, these values would be zero. The difference from absolute matching was small (without punishment, 0.05 for B#327 and 0.02 for

Table 1

Proportion of total responding on the key associated with the lower rate of reinforcement (right key) at each punishment intensity.

	Shock Intensity	*Number of Observations*	*Proportion of Responses on Right Key*	*Difference from No Punishment*	*95% Confident Limits of Difference*
B#327	0	90	0.244		
	3 ma	19	0.258	+0.014	−0.012 to +0.039
	6 ma	23	0.237	−0.007	−0.030 to +0.017
	7.5 ma	20	0.228	−0.016	−0.042 to +0.009
	9 ma	13	0.228	−0.016	−0.047 to +0.016
B#326	0	90	0.207		
	3 ma	8	0.182	−0.024	−0.057 to +0.008
	6 ma	23	0.211	+0.004	−0.016 to +0.024
	7.5 ma	15	0.227	+0.020	−0.005 to +0.045

Table 2
Effect of punishment on rate of reinforcement and matching of response and reinforcement rates.

	Shock Intensity	Reinforcements per Minute Left	Right	Difference Between Proportion of Responses and Reinforcements on the Right Key
B#327	0	0.590	0.140	0.052
	3 ma	0.544	0.130	0.065
	6 ma	0.631	0.124	0.073
	7.5 ma	0.595	0.123	0.057
	9 ma	0.489	0.092	0.070
B#326	0	0.590	0.135	0.021
	3 ma	0.665	0.131	0.017
	6 ma	0.551	0.112	0.042
	7.5 ma	0.494	0.107	0.049

B#326) but it was consistent. This difference was little changed by the punishment (the maximum change was 0.03).

Also of interest is that punishment of two concurrent responses produces the same major sequential changes that occur when a single response is punished. Figure 2 illustrates the phenomena of recovery and compensation (Azrin, 1960*a*; 1960*b*). In the lower portion of the figure the total rate of response (R left + R right/session duration) is plotted for successive sessions. At Session 19, 3-ma punishment was delivered to every response. The introduction of punishment reduced the overall rate of response from the unpunished level of 126 to 20 per min. Over successive sessions, responding increased and appeared to stabilize at a rate of about 100 per min. Removal of punishment at Session 36 led to a brief overshooting of the prepunishment level.

The lowest curve in Fig. 2 shows that the proportion of responses on the key with the lower frequency of reinforcement (right response) remained roughly constant throughout. During the first and second punishment session (Sessions 19 and 20) the proportion of responses on the right key was slightly elevated. Such "over" responding on the seldom-reinforced key was occasionally observed when the rate was greatly suppressed by punishment. However, this did not occur until the rate was below 5% of the prepunishment level and so it could not be assessed reliably.

The curves in the upper half of Fig. 2 are cumulative response records for the two responses during Session 22. Inspection of these curves during the first 45 min of this session reveals the just-noted tendency for both responses to occur at nearly equal rates when suppression was extreme. As responding increased this change in the proportion tended to be washed out. These curves illustrate the recovery observed at the mild and moderate punishment intensities. At higher intensities, responding was uniformly suppressed throughout the session.

DISCUSSION

As punishment intensity increased, the two responses were reduced proportionally even though each response was reinforced at a different rate. The rate of the more-often reinforced response was higher before punishment and remained higher at each punishment intensity. Relative strength of the responses was thus maintained throughout. Proportional suppression, though, was independent of reinforcement rate.

On the surface, these results conflict with the report by Church and Raymond (1967) of greater proportional suppression for the less-often reinforced response. The conditions of the two experiments differed in many respects, but several considerations suggest that the schedules of reinforcement and punishment may be important in resolving the apparent discrepancy.

With two concurrent variable-interval schedules, the number of response instances per reinforcement tends to be the same for both schedules. This follows as an implication of the relative matching relationship between reinforcement and response rates (Revusky,

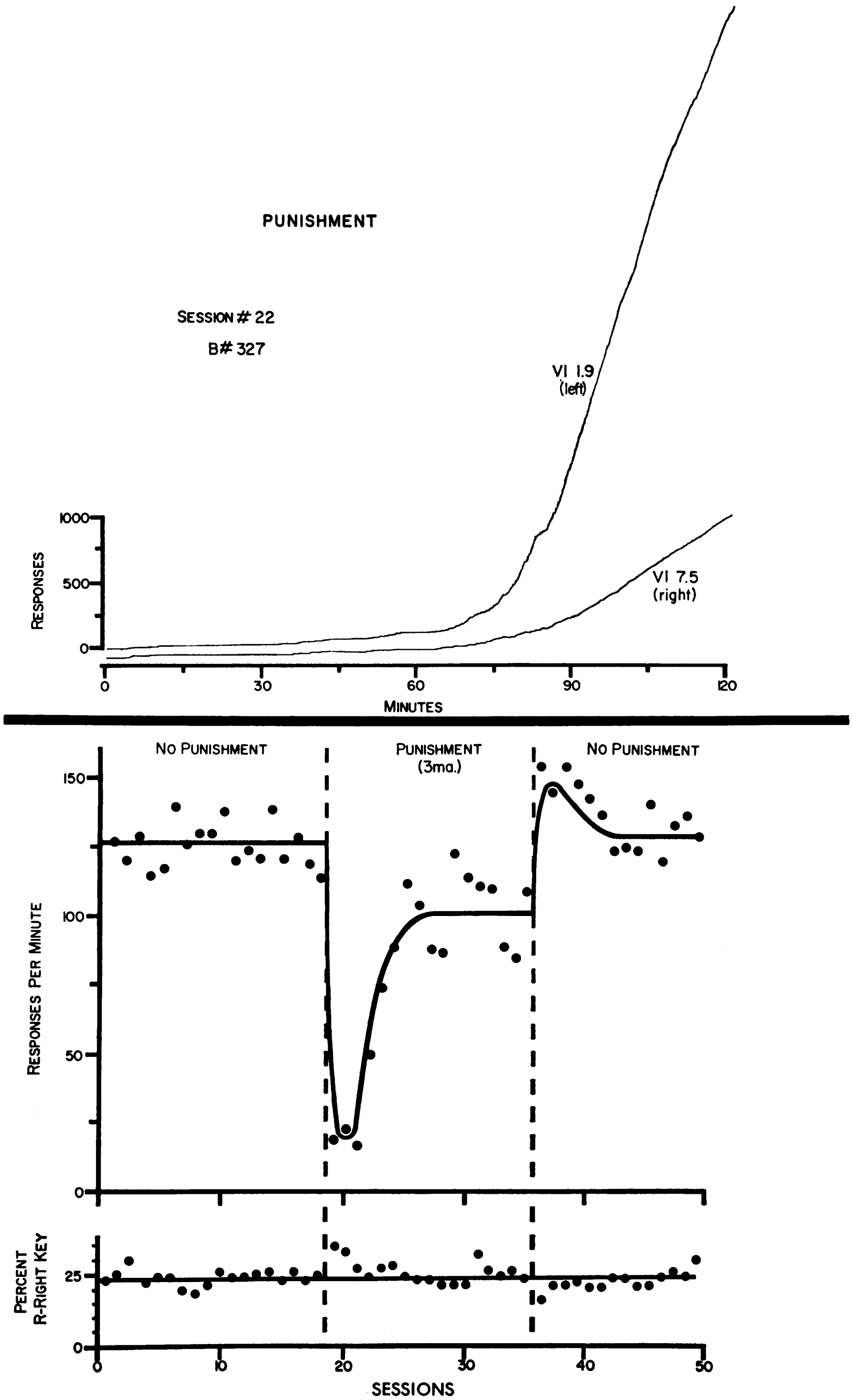

Fig. 2. Recovery and compensation of responding with a mild punishment intensity (3 ma). Upper curves show cumulative response recording from Session 22 for both responses. Lower curves show the session-to-session changes in the total response rate (*i.e.*, the rate of both responses on the *conc* VI 1.9-min, VI 7.5-min schedule) and the per cent of total response on the key with the lower frequency of reinforcement.

1963). Such an equivalence of response instances per reinforcement for both response classes was approximated here (with the limit imposed by the deviation from perfect matching). On the other hand, when two variable-interval schedules are studied separately, the response instances per reinforcement tend to be greater with the lower rate schedule. This is an implication of the negatively accelerated relationship between reinforcement rate and response rate. Such a result appeared in the Church and Raymond experiment. Thus, the two experiments differed in the relative proportion of response instances to reinforcements for the two response classes they studied. A large number of response instances per reinforcement associated with a low rate of reinforcement might represent excess responses. If such excess responses were especially liable to reduction by punishment, this would explain the greater reduction of the response with the lower reinforcement rate found by Church and Raymond. Analysis of punishment's effect on a response maintained by a differential-reinforcement-of-low rate (DRL) schedule of reinforcement (Holz and Azrin, 1962) also suggests that punishment affects excess responses. With the DRL schedule, the response instances associated with short interresponse times, which are never reinforced, are maximally reduced by punishment.

The schedule of punishment is a second major difference between the experiments. Since every peck was punished in the present experiment, the response class that occurred more often received more punishments. But, the number of punishments per reinforcement was similar for both classes, because a similar number of pecks per reinforcement occurred for both classes. The 2-min variable-interval punishment schedule, used in the Church and Raymond experiment, would tend to give the same number of punishments across a range of response rates. This implies a similar number of punishments for each of the two response classes, but more punishments per reinforcement for the response with the lower reinforcement rate. Additionally, the variable-interval schedule would punish a greater proportion of response instances for the response class that had the lower response rate. The effects of differences such as these have not been determined.

In summary, the interactions of punishment and reinforcement schedules may be determinants of the different effects of punishment seen in the two experiments. These interactions also may ultimately prove more important for predicting the effect of punishment than the concept of strength of response.

There is other evidence that rate of reinforcement *per se* does not play a significant role in determining suppression by punishment. Studies of punishment superimposed on various reinforcement schedules have shown rather similar results in the face of large changes in the rate of reinforcement produced by the punishment. This is illustrated in Fig. 3, which has been derived from the data of previously published articles (Azrin, 1959*b*, 1960*a*; Azrin and Holz, 1961; Holz, Azrin, and Ulrich, 1963). Although the experiments used different subjects, they employed very similar punishment procedures. The upper portion of Fig. 3 shows response level as a per cent of the unpunished rate at different punishment intensities. The proportional suppression on all schedules shows remarkable similarity. The rate of reinforcement (lower portion of Fig. 3), on the other hand, was changing drastically as the response was suppressed. On the DRL schedule, the rate of reinforcement increased eightfold, while on the fixed-ratio (FR) schedule the rate of reinforcement necessarily decreased proportionate to response suppression. The FR data present some problem, presented in this way, because the session duration was changing and the response rate observed would depend on the length of the session being considered. Nonetheless, the similarities are striking.

This independence of degree of suppression and rate of positive reinforcement is surprising in view of the large effect food deprivation has on punished responding under similar conditions. Previous experiments (Azrin, 1960*a*; Azrin, Holz, and Hake, 1963) have shown that even a slight decrease in the level of deprivation sharply increases the suppression produced by punishment. Similar changes in deprivation in the absence of punishment have negligible effect upon response rate (Ferster and Skinner, 1957). It would appear that a response occurring at a low rate is readily eliminated by punishment if the low rate is due to low deprivation, but is highly resistant to punishment if the low rate is due to a low rate of reinforcement. This conclusion re-

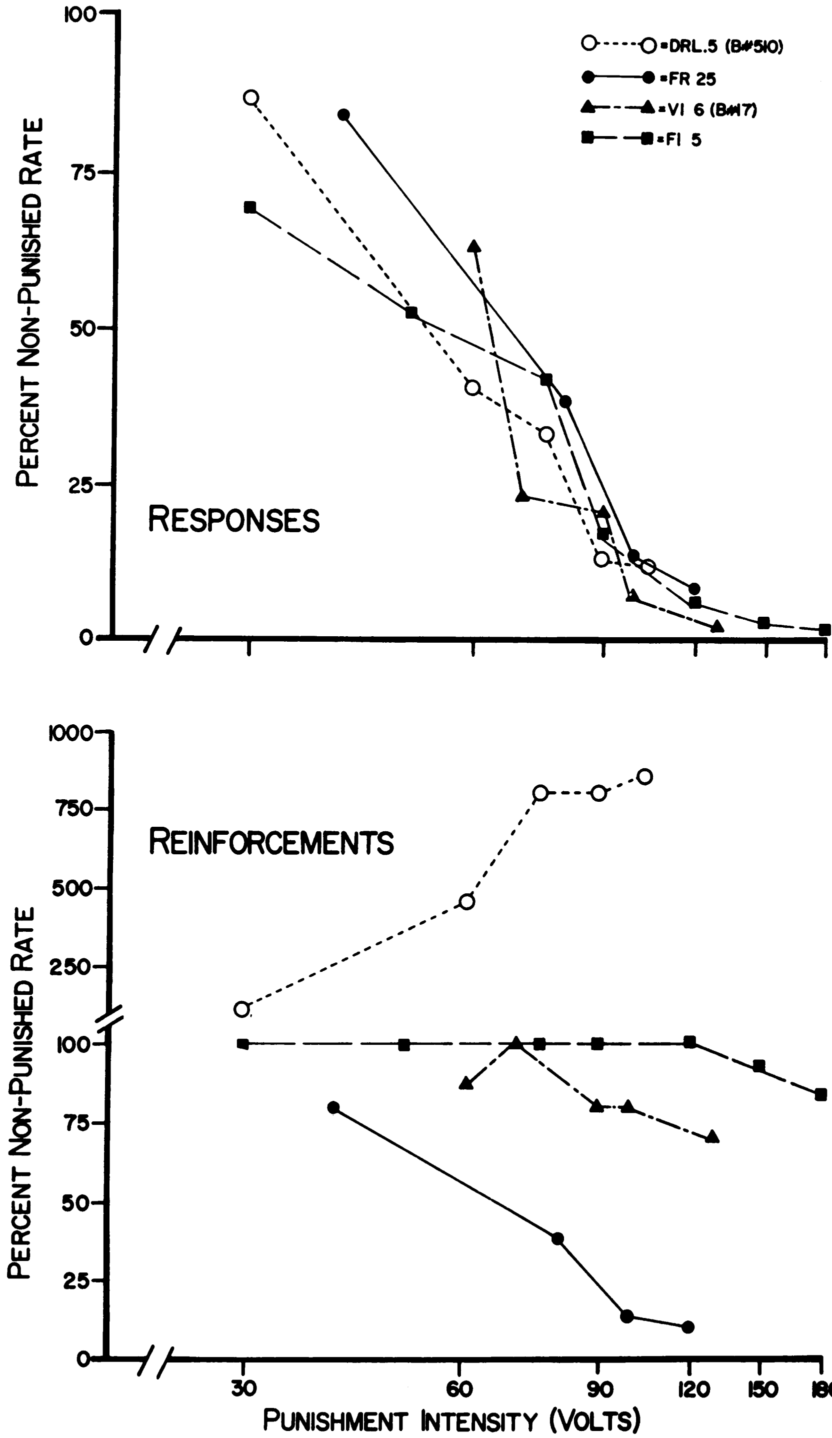

Fig. 3. Comparison of the effect of punishment intensity on responding maintained by fixed-ratio (data from Azrin, 1959*b*), variable-interval (data from Azrin, 1960*a*), fixed-interval (data from Azrin and Holz, 1961) and DRL (data from Holz, Azrin, and Ulrich, 1963) schedules. Response and reinforcement rates are expressed as a percentage of their prepunishment values. The scale on the ordinate has been changed above 100% to allow compact presentation.

sults because a corollary of the independence of punishment and rate of reinforcement is that the same absolute level of punishment will be necessary to eliminate a response regardless of the rate of positive reinforcement.

REFERENCES

Azrin, N. H. A technique for delivering shock to pigeons. *Journal of the Experimental Analysis of Behavior*, 1959, **2**, 161-163. (*a*)

Azrin, N. H. Punishment and recovery during fixed-ratio performance. *Journal of the Experimental Analysis of Behavior*, 1959, **2**, 301-305. (*b*)

Azrin, N. H. Effects of punishment intensity during variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior*, 1960, **3**, 123-142. (*a*)

Azrin, N. H. Sequential effects of punishment. *Science*, 1960, **131**, 605-606. (*b*)

Azrin, N. H. and Holz, W. C. Punishment during fixed-interval reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 343-347.

Azrin, N. H., Holz, W. C., and Hake, D. F. Fixed-ratio punishment. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 141-148.

Catania, A. C. Concurrent performances: a baseline for the study of reinforcement magnitude. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 294-300. (*b*)

Catania, A. C. Concurrent operants. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 213-270.

Church, R. M. The varied effects of punishment on behavior. *Psychological Review*, 1963, **70**, 369-402.

Church, R. M. and Raymond, G. A. Influence of the schedule of positive reinforcement on punished behavior. *Journal of Comparative and Physiological Psychology*, 1967, **63**, 329-332.

Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.

Herrnstein, R. J. Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 267-272.

Holz, W. C. and Azrin, N. H. A comparison of several procedures for eliminating behavior. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 399-406.

Holz, W. C., Azrin, N. H., and Ulrich, R. E. Punishment of temporally spaced responding. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 115-122.

Neuringer, A. J. Effects of reinforcement magnitude on choice and rate of responding. *Journal of the Experimental Analysis of Behavior*, 1967, **10**, 417-424.

Revusky, S. H. A relationship between responses per reinforcement and preference during concurrent VI, VI. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 518.

Solomon, R. L. Punishment. *American Psychologist*, 1964, **19**, 239-253.

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