# PUNISHED AND UNPUNISHED RESPONDING IN MULTIPLE VARIABLE-INTERVAL SCHEDULES[1]

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The performance of rats trained on multiple variable-interval schedules was examined before, during, and after punishment. The same linear function related relative response rates to relative density of reinforcement both in the presence and absence of punishment. Equal relative suppression was seen in both the high and low reinforcement density components. The intercept value of the function was zero. Each component of the schedule was programmed on a separate lever: thus during any component, there was an opportunity for responses on the nonoperative lever (errors). The proportions of these errors declined to a near-zero value during punishment and did not regain their prepunishment values after punishment was removed, suggesting that some discrimination learning occurred during punishment. Recovery of response rate during punishment was seen only where a greater-than-zero probability of reinforcement was associated with the response.

Rate of responding during punishment is affected by variations in reinforcement density. For example, Azrin and Holz (1961) found that rates of punished responding were lower during extinction than during variable-interval (VI) positive reinforcement. Appel (1965) noted that both punished and unpunished rates of pigeons were lower under VI 6-min than under VI 1-min positive reinforcement schedules. In addition, the amount of response suppression shown on a VI punishment schedule was less for rats receiving positive reinforcement on a VI 0.2-min than on a VI 5-min positive reinforcement schedule (Church and Raymond, 1967). While these studies have indicated that positive reinforcement density is a determinant of response rate during punishment, they do not provide detailed information on the nature of the function relating response rate to reinforcement density before and during punishment.

In the present study, rats were trained on two-component multiple schedules of positive reinforcement with different VI values in each component. Relative rate of responding in one component of a multiple schedule has been found to be a function of relative frequency of reinforcement in that component (e.g., Reynolds, 1963). Such an exact relationship between reinforcement density and response rate is not always found when performance is examined under only one reinforcement density at a time (Morse, 1966). If there is no interaction between reinforcement density and punishment intensity, then the same function should relate relative rate of responding to relative density of reinforcement both before and during punishment.

Each component of the multiple schedule was programmed on a separate lever; while reinforcements were available on one lever, extinction was in effect on the other. If the pairing of a primary reinforcer with the punished response is essential to the recovery process, as Williams and Barry (1966) have suggested, then the nonreinforced responses on the nonoperative levers (errors) should show less recovery during punishment than responses on the operative levers.

## METHOD

### Subjects

Six experimentally naive male hooded rats, obtained from Canadian Research Animal Farms, were maintained at 80% of their free-feeding weight. Subjects were approximately 120 days old at the start of the experiment.

*Apparatus*

A standard two-lever Grason-Stadler rat chamber (Model No. E3125B) with one lever located on either side of the food magazine was used in conjunction with a Grason-Stadler shock generator and scrambler (Model No. E1064GS) and appropriate programming devices. Reinforcement consisted of one 45-mg Noyes pellet delivered at appropriate times during the schedule. A response on an operative lever activated a "feedback" relay located behind the magazine wall, producing an audible click.

*Procedure*

Subjects were given 30 min of lever training with both levers present and simultaneously operative: a response on either lever produced a single Noyes pellet. Discriminative stimuli were introduced in the next session. The houselight remained on for 15 min when the left lever was operative, and then off for 15 min with the right lever operative on a regular reinforcement schedule. This procedure was followed for five 30-min sessions. Responses on the operative lever are designated as "correct" responses, those on the nonoperative lever as "errors." The houselight was the sole source of illumination in the test chamber and the room housing the test chamber was always dark.

Assignment of subjects to multiple schedules and schedule components to stimuli is shown in Table 1. For all subjects, the high rein-

forcement-density component was VI 1-min. The low-density component was VI 2-min, 4-min, or 8-min. Component duration was 15 min, and three cycles of the multiple occurred in each 90-min session. The component presented first in any given session was determined according to a prearranged random order with the single restriction that no one component occurred first for more than three consecutive sessions. Reinforcements set up but not collected were erased at the end of the component.

The punishment contingency was introduced after the sixty-fifth session on the multiple schedule, and remained in effect for 45 sessions. During punishment sessions, all responses on the operative and nonoperative levers during both components were always followed by a 0.25-ma electric shock of 100-msec duration. The positive reinforcement schedules remained unchanged. The punishment sessions were followed by 30 no-punishment sessions in which conditions were the same as before punishment.

## RESULTS

Absolute response rates in the high- and low-density components, exclusive of errors, are shown in Fig. 1A, 1B, and 1C. Comparing across subjects, the difference between the rates in the high- and low-density components increased as the difference between the reinforcement schedules increased during acquisition, punishment, and postpunishment ses-
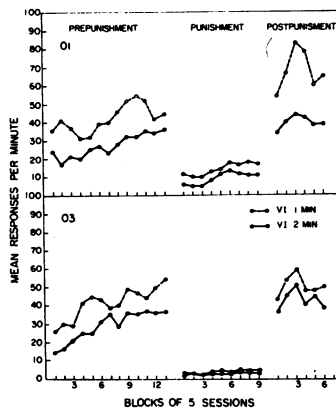


Fig. 1A. Mean response rates over five-day blocks in the VI 1-min and VI 2-min components exclusive of responses on the nonoperative levers.
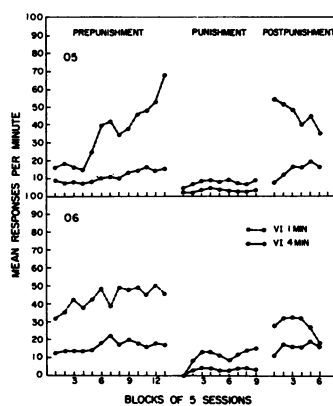
Fig. 1B. Mean response rates over five-day blocks in the VI 1-min and VI 4-min components exclusive of responses on the nonoperative levers.
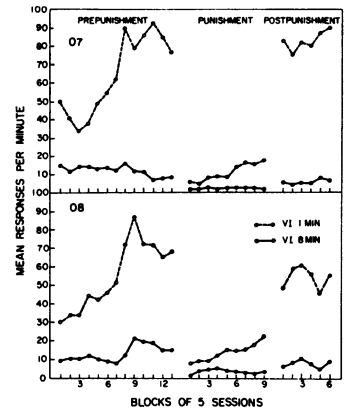
Fig. 1C. Mean response rates over five-day blocks in the VI 1-min and VI 8-min components exclusive of responses on the nonoperative levers.

Table 1
Terminal Rates (Responses Per Minute) for All Conditions

| Light | On | | Off | | |
| Lever | A | B | B | A | Subject |
|---|---|---|---|---|---|
| Schedule | EXT | VI 1 | EXT | VI 2 | |
| Prepunishment | 25.94 | 45.75 | 22.81 | 35.67 | 01 |
| | 16.11 | 49.40 | 14.43 | 36.11 | 03 |
| Punishment | 0.12 | 17.34 | 0.13 | 11.36 | 01 |
| | 0.04 | 4.49 | 0.05 | 3.48 | 03 |
| Postpunishment | 13.00 | 68.10 | 19.37 | 40.10 | 01 |
| | 4.72 | 50.06 | 3.95 | 40.51 | 03 |
| Schedule | EXT | VI 1 | EXT | VI 4 | |
| Prepunishment | 2.32 | 55.93 | 2.10 | 15.31 | 05 |
| | 12.53 | 47.12 | 7.62 | 16.84 | 06 |
| Punishment | 0.05 | 7.81 | 0.05 | 3.22 | 05 |
| | 0.05 | 13.60 | 0.40 | 3.91 | 06 |
| Postpunishment | 1.25 | 31.51 | 7.90 | 16.78 | 05 |
| | 1.07 | 23.58 | 1.73 | 16.35 | 06 |
| Schedule | EXT | VI 1 | EXT | VI 8 | |
| Prepunishment | 2.30 | 85.78 | 5.05 | 8.83 | 07 |
| | 14.49 | 68.52 | 9.12 | 16.64 | 08 |
| Punishment | 0.02 | 16.50 | 0.14 | 2.37 | 07 |
| | 0.25 | 18.57 | 0.36 | 3.06 | 08 |
| Postpunishment | 1.18 | 88.24 | 3.84 | 7.22 | 07 |
| | 5.16 | 49.62 | 4.68 | 7.56 | 08 |

sions. After punishment was removed, response rates in both components tended to return to their prepunishment levels without first overshooting those levels: no punishment contrast effect (Azrin, 1960) was seen.

During punishment, response rates showed the greatest increase from the initial level of suppression in the high reinforcement-density component. Once subjects began responding, rates in the two components remained well separated, with the exception of Subject 03, which also exhibited the lowest over-all response rates during punishment. Terminal response rates for all subjects under each condition are given in Table 1. These are shown as mean responses per minute over the last 15 sessions of each condition.

Total reinforcements were reduced by 20% to 50% for the first 5 to 10 punishment sessions, but proportions of total reinforcements received in the low-density component remained unchanged from prepunishment values. Total reinforcements obtained in all components subsequently returned to their prepunishment levels.

In order to examine performance independent of absolute response rates, correct re-

sponses (responses on the operative lever) during the low-density component were computed for each subject by taking medians of the last 15 sessions of each condition (Fig. 2). These values are virtually identical both before and
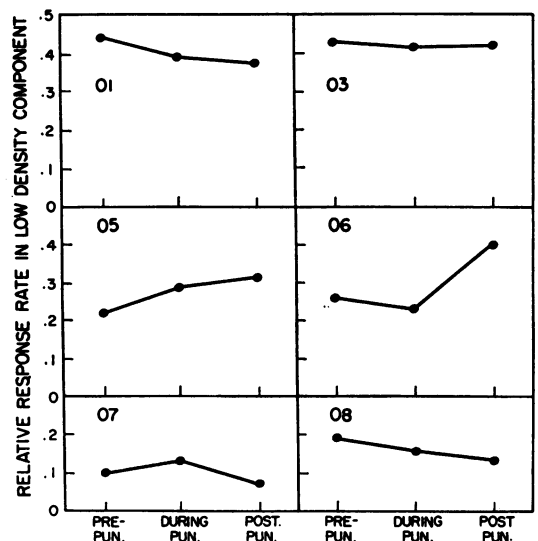


Fig. 2. Relative response rates in low-density component during prepunishment, punishment, and postpunishment conditions.

during punishment for all subjects, indicating that relative response rates remained unchanged after punishment was introduced. The postpunishment values approximate the other two values, with the exception of Subject 06. This discrepancy reflects the sudden and unexplained drop in response rate by Subject 06 in the high-density component during the last 10 postpunishment sessions.

Relative response rates in the low-density components are summarized in Fig. 3 as a function of relative frequency of reinforcement in that component. Data points are individual medians for the last 15 sessions of each condition. Lines were fitted according to the method of least squares. For the three conditions, the zero intercepts and slopes were: prepunishment, −0.01, 1.29; punishment, 0.00, 1.23; postpunishment, 0.00, 1.34.
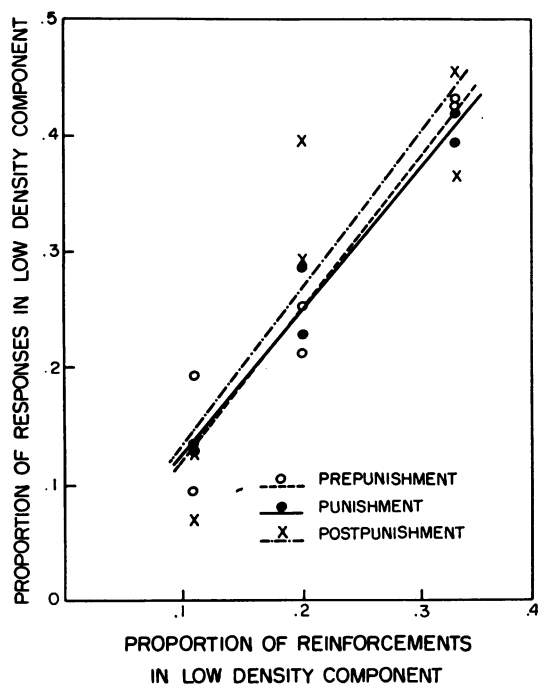


Fig. 3. Proportion of responses on the operative lever in the low reinforcement-density component as a function of proportion of reinforcements in the low reinforcement-density component.

Response rates during punishment are shown as a percentage of terminal prepunishment rates in Fig. 4. Each data point was obtained by taking the mean over five session blocks during punishment according to the following formula:

$$\frac{\text{Punishment rate}}{\text{Punishment rate} + \text{Terminal prepunishment rate}} \times 100.$$

While the curves for the responses on the operative levers gradually increase over sessions, those for errors declined.

A measure of the extent to which the operative lever was discriminated from the nonoperative lever in each component was obtained by taking errors in each component as a proportion of errors plus correct responses in that component. Medians of the last 15 sessions of prepunishment, punishment, and postpunishment for each subject were highly consistent within each multiple schedule condition. The data are therefore shown as means of these medians in Fig. 5. In all cases these discrimination index scores were higher for the low-density components, indicating a higher proportion of errors in that component. The scores drop from a range of 0.097 to 0.346 prepunishment to a range of 0.003 to 0.059 at the end of punishment, indicating less suppression of correct responses than of the nonreinforced errors. After punishment was removed, the discrimination index scores remained lower than before punishment, but higher than during punishment.

## DISCUSSION

Although the introduction of punishment markedly reduced rate of responding, there was no evidence of a long-term disruptive effect on the high-density *vs.* low-density discrimination. During punishment, rates in the high-density component continued to exceed those in the low-density component, except for one subject. As previously mentioned, this subject exhibited the lowest over-all response rates during punishment. Hearst (1965) reported that the introduction of a punishment component to a S+-S− discrimination only temporarily disrupted the discrimination performance of rats. Resumption of responding was associated with reattainment of former levels of discrimination performance, and the poorest discrimination was shown by subjects exhibiting the lowest response rates during punishment.

Greater recovery of response rate from the initial level of suppression imposed by the introduction of punishment always occurred in the high reinforcement-density component (see Fig. 1A, 1B, 1C). This recovery cannot be
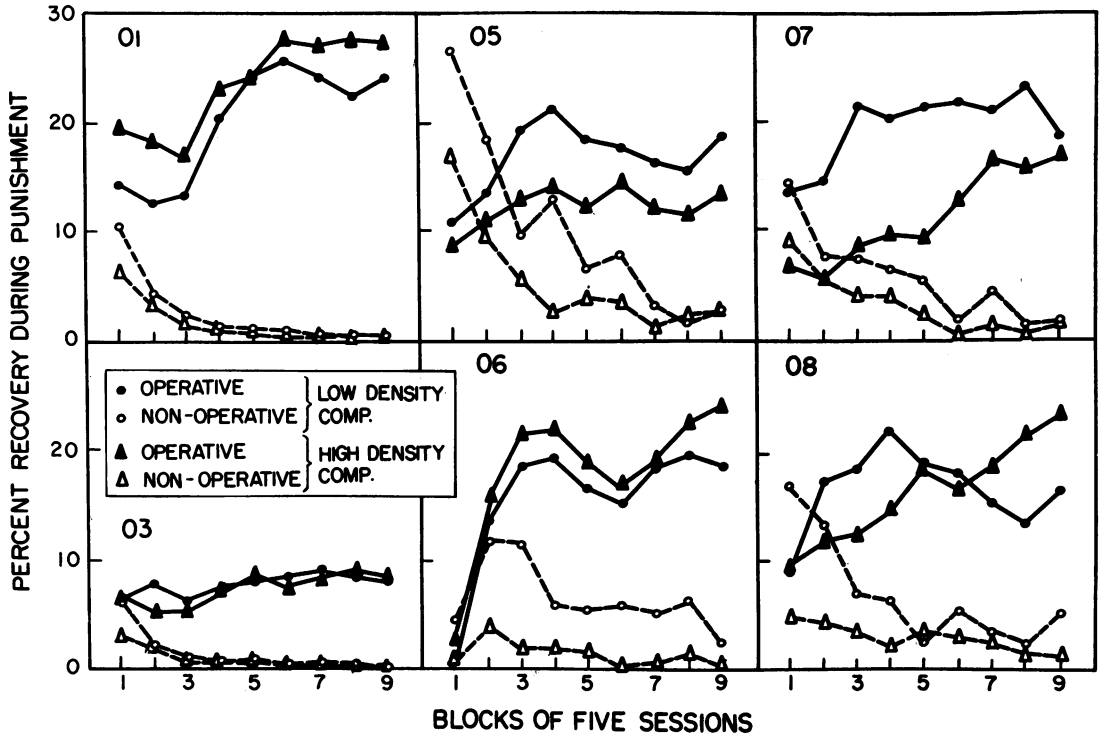
Fig. 4. Recovery during punishment as a function of prepunishment rates.

attributed to a shift in relative reinforcements because reinforcement distributions were unchanged during punishment.

Church and Raymond (1967) reported an interaction between punishment and reinforcement density. A group of rats on a VI 5-min positive reinforcement schedule showed proportionately greater response suppression during punishment than did a group on VI



Fig. 5. Proportion of errors within each component before, during, and after the removal of punishment.

0.2-min. In the present experiment, no subject showed any indication of such an interaction when relative response rates in the low-density components are considered. However, Fig. 5 does suggest such an interaction: here reinforcement density is zero and suppression of errors is greater than suppression of correct responses in each component during punishment. The differences in relative amounts of suppression found with zero and non-zero reinforcement densities are easily seen in Fig. 4. While all response rates are below their prepunishment levels, those responses occurring on levers associated with a greater-than-zero probability of reinforcement continued to increase over punishment sessions. Responses on levers associated with a zero probability of reinforcement declined over sessions. The gradualness of this decline, plus the failure of the error rates to reattain their prepunishment levels after punishment was removed, suggest that the subjects improved in their ability to discriminate reinforcement probabilities.
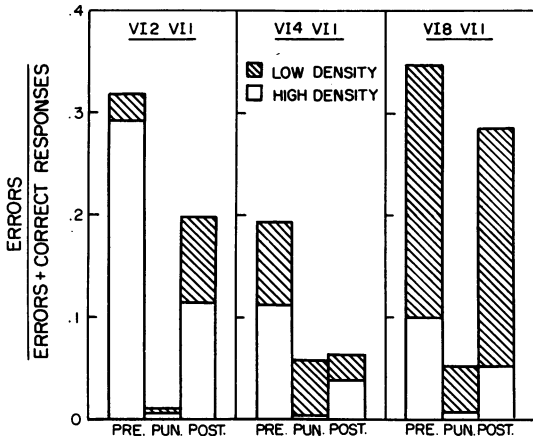
Some methodological differences exist between the present experiment and that of Church and Raymond. In the present study,

all responses were punished; Church and Raymond delivered punishment on a VI 2-min schedule. Furthermore, subjects in the latter study received only five 1-hr training sessions while the present subjects received sixty-five 90-min sessions. The response rates of Church and Raymond's high-density group showed a steady increase over training sessions and do not appear to have reached a stable level when punishment was introduced. The suggestion is that prepunishment rates for this group may be artificially low, thus inflating the suppression ratio calculated during the punishment sessions.

The crucial difference, however, probably lies in the fact that Church and Raymond's subjects were exposed to only one reinforcement schedule. Morse (1966) pointed out that a direct relationship is more often obtained between response rate and reinforcement density when subjects are exposed to more than one reinforcement density in an experimental session. In some manner, such a procedure seems to increase sensitivity to reinforcement.

In view of all these differences, one obviously cannot always predict the effects of punishment in one situation from those seen in another, but dissimilar, situation.

The function obtained for relative response rates (see Fig. 3) differs from those typically obtained with pigeons (*e.g.*, Reynolds, 1963) in that it passes through zero. Reynolds found an intercept value of greater than zero and interpreted this result as indicative of the occurrence of induction of responding from one component to the other. In Reynold's (1963) experiment, only one response lever was used; in the present experiment, each component was programmed on a separate lever. Assuming that this difference is not a species-specific phenomenon, it can be concluded that in the present study, induced responding took the form of errors.

This experiment demonstrates a linear relationship between relative response rate and relative reinforcement density within the range of reinforcement densities used. Appel (1963) has reported that response rates under punishment are an exponential function of shock intensity. For the purposes of direct comparison with the present data, shock intensity should be varied in different components of a multiple schedule in which the amounts of reinforcement received in each component are equal.

## REFERENCES

Appel, J. B. Punishment and shock intensity. *Science*, 1963, **141**, 528-529.

Appel, J. B. Punishment: effects of shock intensity on response suppression. *Psychol. Rep.*, 1965, **16**, 721-730.

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

Azrin, N. H. and Holz, W. C. Punishment during fixed-interval reinforcement. *J. exp. Anal. Behav.*, 1961, **4**, 343-347.

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.

Church, R. M. and Raymond, G. A. Influence of the schedule of positive reinforcement on punished behavior. *J. comp. physiol. Psychol.*, 1967, **63**, 329-332.

Hearst, E. Stress-induced breakdown of an appetitive discrimination. *J. exp. Anal. Behav.*, 1965, **8**, 135-146.

Morse, W. H. Intermittent reinforcement. In W. K. Honig (Ed.) *Operant behavior: areas of research and application.* New York: Appleton-Century-Crofts, 1966. Pp. 52-108.

Reynolds, G. S. Some limitations on behavioral contrast and induction during successive discrimination. *J. exp. Anal. Behav.*, 1963, **6**, 131-139.

Williams, D. R. and Barry, H. III. Counter conditioning in an operant conflict situation. *J. comp. physiol. Psychol.*, 1966, **61**, 154-156.