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CHOICE AND THE RATE OF PUNISHMENT IN CONCURRENT SCHEDULES[1]

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Rats' responses on two levers were reinforced according to independent random-interval 1.5-min food schedules. In addition, both lever presses were intermittently punished according to several concurrent random-interval random-interval shock schedules. For the left, the scheduled rate of punishment was kept constant according to a random-interval 6-min schedule. For the right, the rate of punishment varied. As the frequency of punishment for the right lever press increased, its rate decreased. The rate of the left punished lever press increased, however, even though its scheduled reinforcement rate and punishment rate remained unchanged.

Key words: choice, concurrent schedules, punishment, matching law, lever press, rats

According to Herrnstein's input-output model of operant behavior (Herrnstein, 1970, 1971, 1974), the absolute rate of a response is directly proportional to its relative rate of reinforcement. This is expressed mathematically as:

$$R_1 = k\left(\frac{r_1}{r_0 + r_1 + r_2 + \ldots r_n}\right), \tag{1}$$

where R_1 is the rate of one response, r_1 is the obtained rather than the scheduled reinforcement rate associated with that response, k is a constant, and $r_0 + r_1 + r_2 + \ldots r_n$ represents the sum of the reinforcement rates for all responses. In this equation, r_0 refers to those reinforcers that are not specified by the experimenter, but which are, nevertheless, present in the organism's milieu. The parameter k represents the asymptotic rate of response 1.

The literature on the effects of reinforcement upon singly and concurrently scheduled responses may be accounted for in terms of Equation 1 and its corollaries (see Baum, 1974; Herrnstein, 1970, for reviews). In accordance with Equation 1, if the rate of reinforcement for a pigeon's key pecking remains constant, then increases in the rate of reinforcement from other sources decrease responding (Catania, 1963, 1969; Rachlin and Baum, 1972). For example, in one such study (Catania, 1963), pigeons' pecking was maintained by two independent variable-interval (VI) schedules operating concurrently for two keys. The value of one VI schedule was varied; the value of the second VI schedule was kept constant. As the rate of reinforcement for pecking the first key increased, responding increased. At the same time, however, the rate of responding on the second key decreased, even though its scheduled reinforcement rate remained constant.

When responding is maintained, moreover, by concurrent (*conc*) VI VI schedules of reinforcement, organisms typically match obtained relative rates of reinforcement to relative rates of responding (Herrnstein, 1961, 1970, 1974). This relation is readily derived from Equation 1:

$$\frac{R_1}{R_1 + R_2} = \frac{k\left(\frac{r_1}{r_0 + r_1 + r_2}\right)}{k\left(\frac{r_1}{r_0 + r_1 + r_2}\right) + k\left(\frac{r_2}{r_0 + r_1 + r_2}\right)} = \frac{r_1}{r_1 + r_2}. \tag{2}$$

R_2 denotes the response rate on a second key or lever and r_2 the obtained reinforcement rate associated with that operandum.

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The effects of punishment on concurrent responding, however, have not been studied as much as have the effects of reinforcement. If every response on two keys is punished, the rate of responding on both keys decreases, but the relative rate of responding, regardless of shock intensity, tends to match the relative rate of obtained reinforcement (Holz, 1968; *cf.* Equation 2). In addition, as shock intensity increases, the rate of a punished response decreases, but the rate of a concurrent unpunished response increases (Rachlin and Herrnstein, 1969; Reynolds, 1963).

Punishment has similar effects on responding in multiple schedules. Under a multiple schedule (Ferster and Skinner, 1957), two or more component schedules alternate, each correlated with a different exteroceptive stimulus. Tullis and Walter (1968) obtained results for multiple schedules comparable to those obtained by Holz (1968) for concurrent schedules. The punishment of responding in one component of a multiple schedule, moreover, facilitates either unpunished responses (Brethower and Reynolds, 1962; Terrace, 1968, Experiment 2) or punished responses in a second component (Rachlin, 1966, Experiment 2).

The present study examined the effects of the rate of punishment on concurrently reinforced responding. Two concurrent responses were intermittently reinforced and punished. The scheduled rates of reinforcement for both responses remained equal and constant. For one response, the scheduled rate of punishment remained constant; for the second response, the scheduled rate of punishment varied. As the scheduled rate of punishment of this second response was varied, the effect on the rate of each of the two responses was examined.

METHOD

Subjects

Three male, naive albino Norway rats of the Charles River CD strain, were 147 days old at the start of the experiment. Following free food and water for 28 days, each rat was given a daily ration of 14 g of ground Purina chow mixed with 25 cc of water. Water was always available in each home cage.

Apparatus

Three chambers each had inside dimensions of 23.2 cm by 20.3 cm by 21.9 cm. The floors consisted of 16 stainless-steel bars, with adjacent bars 1.5 cm apart. The front and back were made of aluminum; the two sides and the top were made of transparent acrylic. Attached to the outer surface of the top was a 6-W lamp. Two stainless-steel levers (5.1 cm wide, 1.3 cm thick, 5.1 cm above the floor, and 7.0 cm apart) were symmetrically located on either side of the feeder. Each chamber was enclosed within an insulated box containing a blower, an acrylic window on the side, and a Gerbrands Model D-1 pellet dispenser.

The reinforcers were 45-mg Noyes Precision food pellets. Electric shocks were delivered to both levers, the bars on the floor, and the front and back aluminum sides through an autotransformer, a power transformer, and a 150 K-ohm resister in series with the organism. Lever presses of at least 0.25 N were recorded. A time-shared PDP-12 computer controlled each phase of the experiment and collected the data.

Procedure

Following magazine training and the shaping of both lever presses, responding was maintained by *conc* RI 15-sec RI 15-sec schedules for three sessions, then by *conc* RI 30-sec RI 30-sec schedules for two sessions, and then by *conc* RI 1-min RI 1-min schedules for 25 sessions. Under the last schedules, the mean responses per minute of the final three sessions for the left and right levers, respectively, were: 36.0 and 39.2 (J-1), 26.1 and 26.0 (J-2), and 51.2 and 52.1 (J-3).

For the remainder of the experiment, responding was maintained by *conc* RI 1.5-min RI 1.5-min schedules. At the same time, both responses were punished according to various *conc* RI RI electric-shock schedules. Under the RI reinforcement and RI punishment schedules, responses on a lever were reinforced or punished with a specific probability at the end of every 0.1 sec. The probability was equal to 0.1 divided by the mean interval in seconds (Farmer, 1963; Millenson, 1963). Responses could be simultaneously reinforced and punished. For response 1 (left lever), the scheduled rate of punishment was kept constant at 10 punishments per hour (RI 6-min schedule).

Table 1

Sequence of the scheduled rates of punishment for response 2 and the results at each condition. For all conditions, the scheduled punishment rate for response 1 was 10 punishments per hour. The reinforcement schedules were *conc* RI 1.5-min RI 1.5-min.

Rat	*Sessions*	*Scheduled Punishment Rate for Response 2 (pun/hr)*	*Response Rate (resp/min)* R_1	R_2	*Obtained Reinforcement Rate (rft/hr)* r_1	r_2	*Obtained Punishment Rate (pun/hr)* p_1	p_2	*Changeovers per minute*
J-1	58	10	26.5	24.0	36.7	39.8	10.3	9.2	5.1
	26	15	29.6	26.0	36.0	34.0	10.3	15.7	5.8
	6	0	0.5	59.0	3.7	47.3	2.3	0.0	0.4
	24	5	17.1	35.3	33.7	41.3	9.3	6.0	4.5
	9	20	33.3	32.7	38.7	35.7	9.3	19.7	5.6
	21	0	0.3	63.3	1.7	46.0	1.0	0.0	0.4
	83	10	28.4	21.0	36.7	32.7	11.0	12.0	4.7
	16	20	36.7	12.2	33.3	26.0	8.0	15.0	3.7
J-2	45	10	20.2	20.2	34.5	33.7	9.2	11.0	5.1
	5	0	14.6	23.9	34.7	33.7	10.0	0.0	4.5
	33	5	14.7	19.9	28.3	29.0	7.3	3.0	4.1
	59	15	24.2	41.7	34.0	43.7	10.3	11.3	7.4
	35	0	14.1	24.9	27.3	33.7	12.7	0.0	4.8
	29	10	20.6	20.6	44.7	39.3	11.0	10.3	4.5
	39	20	24.6	20.4	33.3	32.0	10.3	19.3	5.2
	50	15	28.9	19.5	34.3	36.7	12.3	15.7	5.4
J-3	231	10	38.8	28.4	35.0	38.3	10.0	10.7	6.6
	21	0	8.4	39.7	9.7	40.3	2.3	0.0	1.7
	23	5	43.9	32.2	35.7	39.0	12.0	6.7	7.3
	12	20	53.5	30.6	35.3	35.0	10.3	20.0	7.1
	8	15	40.2	23.5	37.0	35.0	9.7	16.0	6.0

For response 2 (right lever), the scheduled rate of punishment was either 0, 5, 10, 15, or 20 punishments per hour (no punishment, RI 12-min, RI 6-min, RI 4-min, and RI 3-min shock schedules, respectively). The sequence of the RI punishment schedules for response 2 was different for each subject (see Table 1, third column).

During Condition 1, for all subjects, the punishment schedule was RI 6-min for each response, and shock intensity was adjusted daily, according to specified rules, so that each subject's response rates would be between 40% and 60% of its prepunishment response rates during the last phase of preliminary training. A preference for a particular lever developed, however, despite the equal scheduled rates of reinforcement and punishment for both responses. A new criterion was then set so that shock intensity was varied until each rat's rates of responding were 60% to 80% of its prepunishment response rates during the last phase of preliminary training.

The final set of rules used to arrive at the criterion response rates were the following for J-1 and J-2: if one or both response rates were above the criterion response rates after a single session, the voltage was increased by 5 V; if after a single session, both response rates were below the criterion, the voltage was decreased by 5 V; if the rate of one response met the criterion and the rate of the second response was below it, the voltage was decreased by 5 V. Using this procedure, shock intensity was set at 90 V for J-1 and at 55 V for J-2, and held at these levels for the remainder of the experiment. The scheduled reinforcement rates for both responses and the scheduled punishment rate for response 1 also were held constant. Thus, only the scheduled rate of punishment for response 2 varied.

During Condition 1, the third subject, J-3, developed a strong preference for the left lever even when criterion response rates were changed to 60 % to 80% of its prepunishment rates. The above-mentioned rules were followed, although occasionally shock intensity was varied as well during the session. The preference still remained, however, with the animal showing great variability in responding from session to session. Finally, a shock intensity of 55 V resulted in a relatively smaller preference for the left lever. The shock intensity for J-3, therefore, remained at that level for the rest of the experiment.

For all subjects, one 2-hr session was initially conducted each day, five days a week. From Session 17 of Condition 2 for J-1, from Session 24 of Condition 3 for J-2, and from Session 75 of Condition 1 for J-3, two 1-hr sessions were usually conducted daily, five days a week, until the experiment ended. A period of about 2 hr elapsed between the daily sessions. The rats were fed after the second session. Each subject was exposed to a particular condition until it appeared that its response rates on the two levers had stabilized over three sessions.

Shock duration was 0.5 sec. Throughout the experiment, a changeover delay of 2 sec was used to minimize the possible control of one response by the consequences of the other response (Catania, 1966; Herrnstein, 1961): 2 sec had to elapse after the subject's changeover to one lever from the other before responding on that lever was reinforced or punished.

RESULTS

Table 1 shows the obtained rates of reinforcement for the two responses, the obtained rates of punishment, and the rates of responding in each condition. Each value represents the mean rate of the last three sessions of each condition. The total number of changeovers per minute from either lever to the other is also given for each condition.

Figure 1 shows the absolute rate of each response plotted as a function of the scheduled rate of punishment on lever 2. If the rat was exposed to a condition twice, the average rates for the two conditions are plotted. (Because of the clear deviance of J-2's rate on lever 2 during Condition 4, only the second determination rates, from Condition 8, are plotted.) As the scheduled rate of punishment on lever 2 increased, the rate of responding on lever 2 decreased. Concomitantly, however, the rate of responding on lever 1 increased, despite the fact that the reinforcement schedule and the punishment schedule for responding on lever 1 remained unchanged.

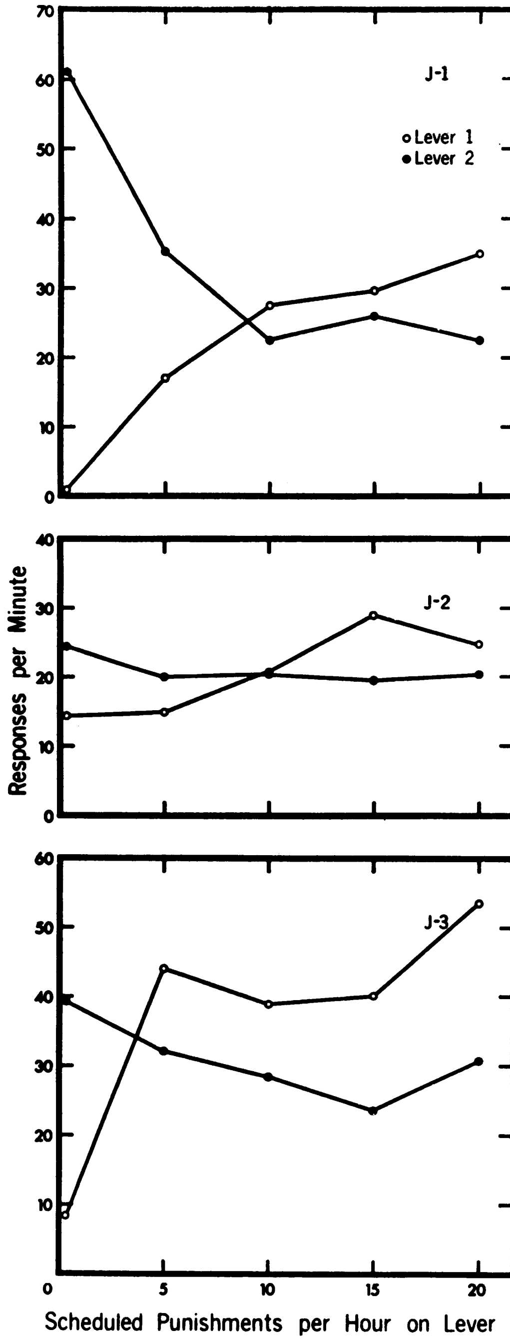

Fig. 1. Rate of responding on levers 1 and 2 as a function of the scheduled rate of punishment on lever 2. For lever 1, the punishment schedule was always RI 6-min.

Although the scheduled rate of reinforcement for each response remained unchanged, the obtained reinforcement rates depended on each lever's response rate and on lever 2's scheduled punishment rate. For J-1, and to a lesser extent for J-3, the obtained lever 1 reinforcement rate increased rapidly to asymptote with increases in its response rate and as the scheduled rate of punishment on lever 2 increased. The obtained lever 2 reinforcement rate tended to increase with increases in its response rate and with decreases in its scheduled punishment rate. This relation did not hold for J-2, perhaps due to the small effect that the punishment rate on lever 2 had on the response rates on both levers (Figure 1).

DISCUSSION

Using *conc* VI VI reinforcement schedules, Catania (1963) found that changes in the rate of reinforcement for one response not only changed the rate of that response, but changed the rate of the other response as well. An increase in the reinforcement rate for one response increased the rate of that response and decreased the rate of the concurrent response, even though the scheduled rate of reinforcement for the second response remained constant. A symmetrical relation exists under *conc* RI RI punishment schedules, as shown in the present study. The scheduled rates of reinforcement for two concurrent responses were equal and remained unchanged; an increase in the scheduled rate of punishment for one response decreased the rate of that response. Concomitantly, the rate of the other punished response increased, even though its scheduled rate of punishment remained the same.

The effects of reinforcement and punishment on concurrent responding in the present study may be expressed as follows:

$$R_1 = k\left(\frac{r_1 + p_2}{r_0 + r_1 + r_2 + p_1 + p_2}\right)$$
$$R_2 = k\left(\frac{r_2 + p_1}{r_0 + r_1 + r_2 + p_1 + p_2}\right), \quad (3)$$

where p_1 denotes the obtained punishment rate for responding on one lever and p_2 denotes the obtained punishment rate for responding on the second lever. Equation 3 predicts that as the rate of punishment of a response increases, the rate of that response decreases and the rate of a concurrently punished response increases, as shown in this experiment.

It may be argued, however, that Equation 3 is flawed, in that it seemingly predicts responding when scheduled reinforcement is absent and only punishment is present. (The unspecified reinforcers, r_0, are still present.) Such a criticism is incorrect if the response has a very low rate of emission in the absence of reinforcement. When the rates of reinforcement for lever pressing are zero ($r_1 = 0$ and $r_2 = 0$), a rat will rarely make a lever press. But if the rat does not respond, punishers will not be delivered. It should be kept in mind that the obtained punishment rates, rather than the scheduled punishment rates, are used in Equation 3. Thus, if lever presses are seldom made in the absence of reinforcement, p_1 and p_2 are both close to zero. Equation 3, therefore, does not predict substantial responding when only punishment is present; rather, in this situation, R_1 and R_2 both approach zero. In this regard, it should be noted that the obtained punishment rates in the present experiment were quite close to the scheduled punishment rates as long as there was some degree of lever responding (see Table 1). Just as there is a feedback relation between response rate and reinforcement rate, in that response rate affects reinforcement rate (Baum, 1973), so too is there a feedback relation between response rate and punishment rate.

The following, moreover, with respect to relative rates of responding, should hold in a two-lever or two-key situation:

$$\frac{R_1}{R_1 + R_2} = \frac{k\left(\frac{r_1 + p_2}{r_0 + r_1 + r_2 + p_1 + p_2}\right)}{k\left(\frac{r_1 + p_2}{r_0 + r_1 + r_2 + p_1 + p_2}\right) + k\left(\frac{r_2 + p_1}{r_0 + r_1 + r_2 + p_1 + p_2}\right)} = \frac{r_1 + p_2}{r_1 + r_2 + p_1 + p_2}. \quad (4)$$

Figure 2 plots the relative rate of responding on lever 1 as a function of its relative rate of reinforcement and punishment over all conditions for all subjects. The solid line represents perfect matching. The broken line in Figure 2 is the best-fitting straight line as determined by the method of least squares. Equation 4 accounts for 88% of the variance; Equation 2 accounts for 81% of the variance.

It should be noted, finally, that Equation 3 assumes that one reinforcer is equal to one punisher in magnitude. That this appeared to be the case in the present experiment may have been due to the mild shock intensity used. But Equation 3 should still account for results obtained with high shock intensities. The effect of shock intensity may be analogous to the effect of deprivation. If animals were re-

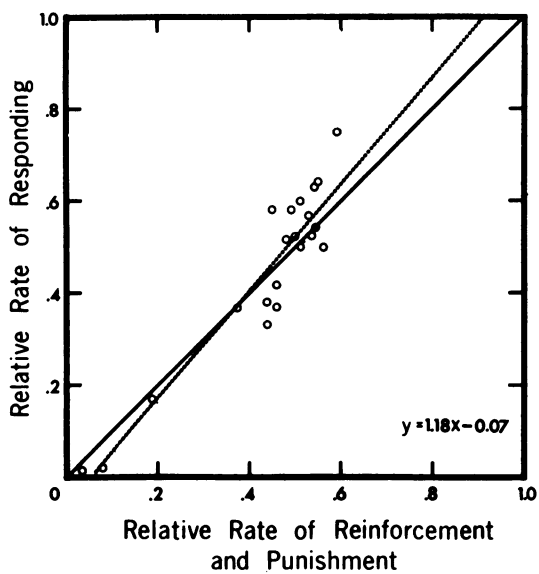

Fig. 2. The relative rate of responding on lever 1 as a function of its relative rate of reinforcement and punishment according to Equation 4. The broken line is the least squares regression line. Perfect matching is indicated by the diagonal.

sponding on *conc* VI VI food schedules, then as deprivation levels decreased, responding should decrease with satiation (*cf.* Clark, 1958; Herrnstein and Loveland, 1974). But this would not refute Equation 1, since if the animals responded less frequently, they would obtain fewer reinforcers. A similar relation may exist for shock intensity. If shock intensity were increased, then responding would decrease (Church, 1969). Yet Equation 3 should still hold, since if the animals responded less frequently, they would obtain fewer reinforcers and punishers.

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