REINFORCEMENT AND RESPONSE RATE INTERACTION IN MULTIPLE RANDOM-INTERVAL AVOIDANCE SCHEDULES¹

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Two experiments were conducted to investigate the interaction between response rate and reinforcement frequency in multiple random-interval avoidance schedules. Responses cancelled delivery of shocks that could be scheduled at different random intervals in each component. When shock-frequency reduction was taken as the measure of reinforcement, the relationship between response rate and frequency of reinforcement was described by the same equations used by Herrnstein (1970) to describe responding with positive reinforcement.

Hineline (1970) pointed out the need for a more general treatment of aversive conditioning procedures analogous to the treatment of behavior maintained by positive reinforcement. The object of the present experiments was to extend the quantitative formulation of the law of effect proposed by Herrnstein (1970) for positive reinforcement to behavior maintained by negative reinforcement (*i.e.*, by the termination or avoidance of aversive stimulation). Herrnstein derived a set of functions from observed correlations between the rate of responding and rate or magnitude of reinforcement on single, multiple, and concurrent variable-interval (VI) schedules of reinforcement. These equations are intended to account for interactions between both successive and simultaneous conditions of reinforcement as regards response frequency.

However, the common avoidance schedules used in free operant research are inappropriate for similarly determining the relations between response rate and negative reinforcement variables. In order to reflect reinforcement value, response rate must be free to vary. However, in procedures such as the standard

Sidman avoidance (1953) or Sidman's adjusting schedule (1962), response rate is largely determined by regularities in the temporal relations between shocks and responses. These regularities and their effects on response rate and interresponse time distribution have been ably demonstrated by Anger (1963). Response rate on schedules like these would not vary widely with changes in rate and magnitude of reinforcement for avoidance behavior, whether such reinforcement is considered to be shock-frequency reduction (Sidman, 1962; Herrnstein, 1969), or the removal of conditioned aversive stimuli (Anger, 1963). When a particular response rate is differentially reinforced, as in DRL or "paced" schedules or in standard avoidance, it is not an appropriate index of reinforcement value.

The quantitative interactions among shock rate, shock-frequency reduction, and response rate in single and multiple avoidance schedules were investigated by developing a random-interval avoidance schedule that eliminated fixed temporal relations between responses and shocks, but still allowed both shock rate and shock frequency reduction to be measured.

METHOD

Subjects

Five experimentally naive male Lashley-strain rats were approximately five months old at the beginning of the experiments. Three were used in Experiment I (R5, R10, and R12), and two in Experiment II (R15 and

¹The author wishes to thank Dr. R. J. Herrnstein for his ready and valuable advice during the research and the preparation of this manuscript. Thanks are also due to Mrs. A. Papp and Mrs. V. Peterson for their assistance in the care of the animals. This research was supported by a grant from the National Institute of Mental Health to Harvard University. Reprints may be obtained from the author, Psychology Department, Harvard University, William James Hall, 33 Kirkland Street, Cambridge, Mass. 02138.

R18). The rats had free access to food and water in their home cage.

Apparatus

The experimental chamber for both experiments was a standard rat box 9 in. long, 8 in. wide and 7.5 in. high (23 by 21 by 20 cm), with metal ends, Plexiglas sides and ceiling, and illuminated by a red houselight. A response lever was mounted in the middle of the front panel 2.5 in. (6.5 cm) above the grid floor. The floor grids were 0.75 in. (0.6 cm) in diameter and spaced 1 in. (2.54 cm) apart center-to-center. The lever and metal ends of the chamber, as well as the floor grids, were in the shock circuit.

A probability generator (Lehigh Valley Electronics Co.), pulsed every 1.75 sec by a recycling timer, generated a random sequence of shocks at a fixed probability for each experimental condition. Alternating current shocks from a constant current shock source passed through a scrambling device, thence to the floor, lever, and metal walls.

The presence or absence of a buzzer signalled the components of the multiple schedule. Conventional electro-mechanical circuitry controlled the stimulus events and recorded the data on counters. Supplementary data were recorded on a Gerbrands cumulative recorder.

EXPERIMENT I

Procedure

Sessions were 2.5 hr in duration, with data collected from the last 1.5 hr. Shock intensity was 1.5 mA; shock duration, 0.3 sec.

All three rats first received five sessions on a Sidman avoidance schedule with a shock-shock interval of 6 sec and a response-shock interval of 12 sec.

Next, the schedule was changed to a random-interval (RI) avoidance schedule. Shocks were now scheduled randomly by a probability generator pulsed every 1.75 sec and set at some fixed probability of output. The minimum shock-shock interval was 1.75 sec and the mean inter-shock interval depended jointly on this minimum interval and the constant probability of shock. The quotient of the pulse rate divided by the probability gives the average shock-shock interval.

The first response made after a scheduled shock prevented the presentation of only the

next scheduled shock. Extra responses between two scheduled shocks did not avoid further shocks or build up a delay of shock.

The three rats were then given the procedure outlined in Table 1: R5 had originally been trained on an RI 12-sec (2.4-sec pulse rate at $p = 0.2$) in an earlier pilot study of the RI avoidance schedule so it entered the procedure at the multiple RI 15-sec RI 15-sec phase. R12 broke its teeth in the bars of its home cage before the second single RI 15-sec condition and had to be destroyed.

Table 1

Number of sessions in each experimental condition of Experiment I for R10, R5, and R12.

Schedule	Number of Sessions		
	R10	R5	R12
Single RI 15-sec (1.75 sec pulse rate at $p = 0.12$)	10		10
Multiple RI 15-sec RI 15-sec	8	8	8
Multiple RI 15-sec RI 60-sec (1.75 sec at $p = 0.029$)	15	15	15
Single RI 15-sec	10	10	
Single RI 30-sec (1.75 sec at $p = 0.058$)	10	10	

The two components of the multiple schedule were each 3 min in duration, and the component in which scheduled shock rate remained unchanged was signalled by a buzzer.

RESULTS AND DISCUSSION

All three animals showed stable high response rates on the RI 15-sec schedule and almost the same single RI 15-sec response rate was obtained before and after the multiple schedule phase of the experiment for R10, the only subject for which the comparison is possible. Received shock rate was fairly constant over sessions for any given RI value.

Bursts of very short interresponse times (< 1.0 sec) were found immediately after a shock was presented, but not at any other time. The conditional probability of responding at any interval of time after the post-shock response bursts showed no consistent trend up or down. However, since the animals were given 10 or fewer sessions on any one RI schedule, there may have been insufficient time for the emergence of any fine temporal patterning.

As is shown in comparing the second and third panels of Figure 1, a marked temporary contrast effect was found in response rate in

Fig. 1. Session-by-session response rates for R10, R5, and R12 for each phase of Experiment I. Response rates for all 15 sessions of the multiple RI 15-sec RI 60-sec phase and for the last five sessions of each of the other experimental conditions are shown. The open squares represent response rate on the single RI schedules, RI 15-sec and RI 30-sec. The open circles represent response rate in the buzzer component (unchanged component) of the multiple schedule, RI 15-sec in each condition. The crosses and broken line represent response rate in the second component of the multiple schedule, RI 15-sec and then RI 60-sec.

the unchanged component (solid line) of the multiple schedule when the second component (dashed line) was changed from RI 15-sec to RI 60-sec. By the seventh session after the change in schedule, response rate in the unchanged component had returned to a stable level between two and four responses per minute higher than it had been during the multiple RI 15-sec RI 15-sec phase. This relatively long-term contrast effect (Bloomfield, 1967), though small, was consistent. In no session did response rate here drop below the level in any of the last four sessions of the multiple RI 15-sec RI 15-sec.

Response rate in the changed component fell off rapidly. Indeed, it was approximately the same in Session 1 as in Session 15 of the contrast phase (third panel). For R5 and R10, an increase in response rate in the RI 60-sec component accompanied the large positive contrast obtained in the RI 15-sec component. R12 also showed a slightly increased response rate during Sessions 2 and 3 of this phase, but then responding dropped while positive contrast in the other component continued. This phenomenon was investigated further in the second experiment.

Herrnstein (1970) suggested that in multiple VI schedules of positive reinforcement, the equation

$$P_1 = \frac{kR_1}{R_1 + mR_2 + R_0} \tag{1}$$

may account for the long-term contrast effect in each component. In this equation, R_1 is the frequency of reinforcement in the component in question and R_2 reinforcement frequency in the other component; k is the asymptotic response rate when there is no reinforcement for any competing responses; m is a parameter indicating the degree of interaction between

the reinforcement conditions of the two components of the schedule, and R_0 represents the total reinforcement for other responses in the experimental situation.

Mean response rates, obtained shock rates, and shock-frequency reductions (scheduled shock rate minus observed shock rate) over the last three sessions in the two multiple schedule conditions were calculated for the buzzer (*i.e.*, the unchanged) component in the multiple RI 15-sec RI 15-sec schedule and for each component in the multiple RI 15-sec RI 60-sec schedule. The three equations obtained by fitting equation 1 to the data from each of these components were then solved to obtain the three unknown parameters, k , m , and R_0 . There is, however, some dispute over the definition of reinforcement for avoidance behavior (for example, Anger, 1963; Herrnstein, 1969). Consequently, equation 1 was fitted twice to response rate in each component; once with observed shock rates as measure of reinforcement and once with shock-frequency reduction as the measure. Observed shock rates seem to be a plausible measure of the conditioned aversive stimulation called for by two-factor theories (such as Anger's), while shock-frequency reduction is specifically the measure called for by Herrnstein's account. The exact values for each of the three parameters thus derived for each rat are shown in Table 2.

Herrnstein has shown that the equation

$$P_1 = \frac{kR_1}{R_1 + R_0} \tag{2}$$

describes response rate on single VI schedules of positive reinforcement. It could therefore be determined whether the set of equations proposed by Herrnstein also accounted for response rate/reinforcement frequency interactions on RI avoidance schedules, by using the

Table 2

Values for the parameters k , R_0 , and m for each rat in Experiment I derived by using either shock-frequency reduction or received shock rate as the frequency reinforcement for the avoidance behavior.

		R10	R5	R12	
Shock-frequency Reduction as Reinforcement.	k	24.4	42.7	55.1	Responses per min
	m	0.23	0.28	0.17	
	R ₀	0.35	1.60	1.34	Shocks avoided per min
Received Shock Rate as Reinforcement.	k	29.4	34.1	56.2	Responses per min
	m	0.41	0.34	0.21	
	R ₀	0.14	0.04	0.23	Shocks per min

derived parameters shown in Table 2 to predict subsequent response rate or account for prior response rate on different single RI schedules given the observed shock rates and shock-frequency reductions. Equation 2 was solved using the observed shock rates and shock-frequency reductions from the single RI 15-sec and RI 30-sec schedules for each rat and their corresponding k and R_0 value from Table 2. The predicted response rates thus obtained were then compared to the observed response rates on these schedules.

Table 3 demonstrates that this quantitative formulation of the law of effect for positive reinforcement can be extended to response rate/reinforcement rate interactions for negative reinforcement if the reinforcement for avoidance is measured in terms of shock-frequency reduction. The most inaccurate pre-

diction of single RI response rate was found in the case of the RI 30-sec for R5. Here, the parameters derived from the multiple schedule data using shock-frequency reduction predict a response rate about three responses per minute too high. The mean deviation of predicted from observed response rate with shock-frequency reduction as reinforcement, summarized over all rats and all conditions, was 1.2 responses per minute too high, or 5.5% of observed response rate.

The predicted values from obtained shock rate, on the other hand, are consistently too high for the single RI 15-sec schedule, and in the case of R5 on the RI 30-sec schedule predict a response rate more than 10 responses per minute too high. Mean deviation of predicted from observed response rate with shock rate as the measure of reinforcement, again

Table 3

Observed and predicted response rates on the single RI 15-sec and single RI 30-sec schedules for the observed shock rate or shock frequency reduction. Values for the last three sessions and the mean of these three sessions for each schedule are shown.

						PREDICTED RESPONSE RATE (per min)				
						BY SHOCK RATE		BY SHOCK-FREQUENCY REDUCTION		
		SESSION	SHOCK RATE (Shocks per min)	SHOCK-FREQUENCY REDUCTION (Shocks avoided per min)	OBSERVED RESPONSE RATE (per min)					
R10.	Single RI 15-sec	8	0.66	3.34	22.9	24.3	(+1.4)	22.1	(-0.8)	
		9	0.96	2.91	20.8	25.7	(+4.9)	21.8	(+1.0)	
		(Before Contrast) 10	0.71	3.43	22.8	24.6	(+1.8)	22.2	(-0.6)	
	Mean		0.78	3.23	22.2	24.9	(+2.7)	22.0	(-0.2)	
	(After Contrast)	8	0.74	3.32	22.7	24.7	(+2.0)	22.1	(-0.6)	
		9	0.65	3.42	22.5	24.2	(+1.7)	22.2	(-0.3)	
		10	1.07	3.42	21.9	26.0	(+4.1)	22.2	(+0.3)	
	Mean		0.82	3.39	22.4	25.1	(+2.7)	22.2	(-0.2)	
	Single RI 30-sec	8	0.24	1.69	17.4	18.6	(+1.2)	20.3	(+2.9)	
		9	0.35	1.82	19.8	21.0	(+1.2)	20.5	(+0.7)	
		10	0.23	1.91	17.9	18.4	(+0.5)	20.7	(+2.8)	
	Mean		0.27	1.81	18.4	19.5	(+1.1)	20.5	(+2.1)	
R5.	Single RI 15-sec	8	0.44	3.68	28.1	31.4	(+3.3)	29.7	(+1.6)	
		9	0.58	3.60	29.2	32.0	(+2.8)	29.6	(+0.4)	
		(After Contrast) 10	0.46	3.54	29.5	31.5	(+2.0)	29.4	(-0.1)	
	Mean		0.49	3.61	28.9	31.7	(+2.8)	29.6	(+0.7)	
	Single RI 30-sec	8	0.19	1.59	18.7	28.3	(+9.6)	21.3	(+2.6)	
		9	0.21	1.65	17.2	28.8	(+11.6)	21.7	(+4.5)	
		10	0.19	1.63	19.2	28.3	(+9.1)	21.6	(+2.4)	
	Mean		0.20	1.62	18.4	28.6	(+10.2)	21.5	(+3.1)	
	R12.	Single RI 15-sec	8	0.79	3.07	36.3	43.4	(+7.1)	38.3	(+2.0)
			9	0.65	3.58	38.3	41.4	(+3.1)	40.0	(+1.7)
			(Before Contrast) 10	0.66	3.43	38.1	41.5	(+3.4)	39.5	(+1.4)
		Mean		0.70	3.36	37.6	42.2	(+4.6)	39.3	(+1.7)

summarized over all rats and conditions, was 4.0 responses per minute, or 17.9% of observed response rate.

EXPERIMENT II

Procedure

Sessions were 2 hr in duration with data being taken from the last hour. Shock intensity was 1.5 mA; shock duration, 0.3 sec.

The two rats (R15 and R18) had been trained on an RI 16.7-sec (1.67 sec at $p = 0.10$) in another experimental chamber for approximately 10 sessions. Then they were transferred to the experimental chamber described for Experiment I and given the procedure outline in Table 4:

Table 4

Number of sessions in each experimental condition of Experiment II for R18 and R15.

Schedule	Number of Sessions	
	R18	R15
Multiple RI 30-sec RI 30-sec	7	7
Multiple RI 30-sec RI 15-sec	14	14
Multiple RI 30-sec RI 30-sec	6	6
Single RI 15-sec	8	

The unchanged RI 30-sec component of the multiple schedule was signalled by a buzzer, and each component was 3 min in duration.

RESULTS

The session-by-session results are summarized in Figure 2. The second panel from the left indicates that when the second component (dashed line) of the multiple schedule was changed to RI 15-sec, causing an increase in responding in that component, both rats first showed a generalized increase in response rate in the RI 30-sec component (solid line) as well.

This was a transitory effect, lasting only three sessions for R15 and six sessions for R18. Both rats then showed a negative contrast effect *i.e.*, a decrease in response rate in the unchanged RI 30-sec component. Response rate was fairly stable at two to four responses per minute lower than that obtained in the multiple RI 30-sec RI 30-sec schedule. This decrease in response rate resulted in a slight increase in shock rate in the RI 30-sec component for R18, from a mean of 0.37 to 0.43 shocks per minute for the last three sessions of the multiple schedule procedures. Shock rate in the RI 30-sec component for R15 was actually slightly lower in the negative contrast phase of the experiment.

Mean response rates, shock rates, and shock-frequency reductions for the last three sessions of the contrast phase and the multiple RI 30-sec RI 30-sec phase were calculated. These values were again fitted to Herrnstein's equation for multiple schedule interactions and values for the parameters k , m , and R_0 were derived.

Table 5 shows that values similar to those found in Experiment I were derived when shock-frequency reduction was used as the measure of reinforcement. However when observed shock rate was used, an unlikely, if not impossible, solution was derived for R15: m was found to be negative, which implies that a long-term increase in the RI 30-sec component response rate should occur when shock rate in the second component is increased from RI 30-sec to RI 15-sec. In fact, a decrease in response rate was observed. The value derived for k was also improbably high.

The parameters k and R_0 derived for R18 were used to predict single response rate for R18 given the observed shock rate and shock-frequency reduction. Observed response rates and predicted response rates are shown in Table 6.

Table 5

Values for the parameters k , R_0 , and m for both rats in Experiment II, derived by using either shock-frequency reduction or received shock rate as the frequency of reinforcement.

		R18	R15	
Shock-frequency Reduction as Reinforcement	k	28.9	46.7	Responses per min
	m	0.30	0.50	
	R_0	1.00	1.60	Shocks avoided per min
Received Shock Rate as Reinforcement	k	29.0	111.8	Responses per min
	m	0.42	-0.32	
	R_0	0.26	1.40	Shocks per min

Fig. 2. Session-by-session response rate for R15 and R18 in Experiment II. Response rates for all 14 sessions of the multiple RI 30-sec RI 15-sec and all six sessions of the post-contrast multiple RI 30-sec RI 30-sec phases are shown. The open circles represent response rates in the buzzer (unchanged) component of the multiple schedule, RI 30-sec in each condition. The crosses represent response rates in the second component of the multiple schedule, RI 30-sec, then RI 15-sec, and then RI 30-sec again. The open squares represent response rates on the single RI 15-sec schedule for R18. The dotted line in the second panel represents the mean response rate in the buzzer component for the last three sessions of the multiple RI 30-sec RI 30-sec before the second component was changed to RI 15-sec.

Table 6

Observed and predicted response rates on the single RI 15-sec schedule for R18 for the observed shock rate or shock-frequency reduction. Values for the last three sessions and the mean of those sessions are shown.

						PREDICTED RESPONSE RATE (per min)			
			SHOCK RATE (Shocks per min)	SHOCK- FREQUENCY REDUCTION (Shocks avoided per min)	OBSERVED RESPONSE RATE (per min)	BY SHOCK- FREQUENCY REDUCTION			
SES- SION						BY SHOCK RATE			
R18. Single RI 15-sec	6	0.54	2.95	19.7	19.6	(−0.1)	21.5	(+1.8)	
	7	1.24	3.19	22.7	24.0	(+1.3)	22.0	(−0.7)	
	8	0.88	2.97	21.1	22.4	(+1.3)	21.6	(+0.5)	
	Mean	0.89	3.04	21.2	22.5	(+1.3)	21.7	(+0.5)	

Once again, the parameters derived using shock-frequency reduction provide the more accurate quantitative account of the interactions between response rate and reinforcement frequency, although the difference is small. Predictions were not made for response rate on the initial RI 16.7-sec training schedule because the rats were trained in a different experimental chamber, and the RI 16.7-sec had a different minimum shock-shock interval.

DISCUSSION

The first experiment demonstrated that both a transitory and a long-term, stable positive contrast effect are found in multiple RI avoidance schedules, as in multiple VI schedules of positive reinforcement (Bloomfield, 1967; Herrnstein, 1970). In Experiment II, however, a transitory increased response rate was followed by a negative contrast. The long-term contrast effects confirm the finding by Wertheim (1965), who found that response rate in the first component of a multiple Sidman avoidance schedule varies inversely with shock rate in the second component. On the other hand, the transitory facilitation of response rate in the unchanged component in the second experiment is similar to the results obtained by Appel (1960). Appel found generalization rather than contrast between the two components of a multiple Sidman avoidance schedule. The temporary facilitation of response rate found in Experiment II may be the result of an initial failure to discriminate the two components when the scheduled shock rate in the second component is suddenly increased.

The quantitative results of these two experiments demonstrate a lawful relationship between response rate and shock-frequency reduction on RI avoidance schedules. Indeed, these results suggest a parallel between positive and negative reinforcement as regards the function between response strength and frequency of either positive or negative reinforcement if negative reinforcement is taken as shock-frequency reduction. It must be noted that Herrnstein (1970) stressed the fact that his equations are based on observed reinforcement frequency and not scheduled rate of reinforcement. Yet, the shock-frequency reduction measure used in these experiments was obtained by subtracting received shock

rate from scheduled rate of shock. This measure has pragmatic justification in that it accurately accounts for observed response rate on different single RI schedules, as well as accounting for the interaction between successive conditions of reinforcement in a multiple schedule. Moreover, it may be argued that while in the case of positive reinforcement the animal can experience only the received reinforcement rate, in an avoidance schedule the animal comes into contact with the scheduled shock rate in the "warm-up" period that is characteristic of every session on free operant avoidance schedules (Sidman, 1966), and in any long pause in responding.

Shock rate was also used as a possible measure of reinforcement because this could serve as a first approximation to a measure of the aversiveness of postulated conditioned stimuli associated with non-responding, or of any conditioned aversive state of the organism. The more straightforward two-factor theory of avoidance (Mowrer and Lamoreaux, 1946; Schoenfeld, 1950; Rescorla and Solomon, 1967) holds that the removal of these aversive stimuli or states by a response reinforces that response. Wertheim (1965) also found that response rate in the first component of a multiple Sidman avoidance schedule was some monotonic function of shock rate in the second component. However, it is clear from the data obtained in both present experiments that received rate of shock does not account adequately for response rate on RI avoidance schedules if Herrnstein's equation for multiple VI schedules of positive reinforcement is extended to multiple RI avoidance schedules. Nevertheless, it can easily be argued by proponents of a two-factor theory of avoidance that asymptotic shock rate is not an appropriate measure of the aversiveness of the postulated mediating stimuli, and shock rate may be a better predictor of response rate given some other theoretical formulation relating response rate to reinforcement in avoidance schedules.

The important finding of the present experiments is not that two-factor theory cannot qualitatively account for the results, but rather that the relationship between response rate and negative reinforcement in random-interval avoidance schedules is accurately described by the formulation of the law of effect developed by Herrnstein for positive reinforcement,

using shock-frequency reduction as the reinforcement for avoidance responding.

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Received 3 November 1971.

(Final acceptance 5 July 1972.)