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EFFECTS OF REINFORCEMENT MAGNITUDE ON INTERVAL AND RATIO SCHEDULES[1]

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Rats' lever pressing was studied on three schedules of reinforcement: fixed interval, response-initiated fixed interval, and fixed ratio. In testing, concentration of the milk reinforcer was varied within each session. On all schedules, duration of the postreinforcement pause was an increasing function of the concentration of the preceding reinforcer. The running rate (response rate calculated by excluding the postreinforcement pauses) increased linearly as a function of the preceding magnitude of reinforcement on fixed interval, showed slight increases for two of the three animals on response-initiated fixed interval, and did not change systematically on fixed ratio. In all cases, the overall response rate either declined or showed no effect of concentration. The major effect of increasing the reinforcement magnitude was in determining the duration of the following postreinforcement pause, and changes in the response rate reflected this main effect.

Early investigations of the relationship between the magnitude of reinforcement and the rate of responding or running speed have suggested that increasing the former would increase the latter. This phenomenon was reported both with free-operant responding (Guttman, 1953) and with runway performance (Crespi, 1942; Zeaman, 1949). The findings seemed to be straightforward and consistent with commonsense notions of the effects of reinforcement. The rapid shifts in performance, produced by changing the magnitude, were attributed by most theorists to concomitant changes in motivation (*cf.* Bartoshuk, 1971). Subsequent research has shown, however, that the relationships involved are more complex than previously thought, and several reviews of the literature have indicated that at present the evidence is inconclusive (Bolles and Moot, 1972; Kling and Schrier, 1971; Neuringer, 1967).

For example, Guttman (1953) found that on a fixed-interval (FI) schedule, the overall response rate was a direct function of the concentration of the sucrose solution used as reinforcer. Although this has been confirmed by several studies (Collier and Myers, 1961; Collier and Willis, 1961; Hutt, 1954; Stebbins, Mead, and Martin, 1959), changing the amount of the reinforcer has been found not to affect the response rate on an FI schedule (Keesey and Kling, 1961). In the case of the fixed-ratio (FR) schedule, Powell (1969) found a direct relationship between the amount of reinforcer and response rate, whereas Hurwitz, Walker, Salmon, and Packham (1965) found this relationship to be inverse when the concentration of a sucrose solution was manipulated.

This apparent inconsistency in the literature probably arises from a confusion of two main functions that a reinforcing stimulus may have. Recent evidence suggests that greater magnitude of reinforcement, apart from having motivational effects, may also inhibit or depress responding immediately after it occurs. Staddon (1970), investigating the effect of the duration of grain presentation on the performance of pigeons on an FI schedule, found that when a longer reinforcer duration initiated an interval, both the overall response rate and the running rate (*i.e.*, the rate calculated by taking into account only the time from the first response in each interval to the next reinforcement) were lower, and the postreinforcement pause was longer. Similar effects of the magnitude of the preceding reinforcer have been reported in numerous runway studies (*cf.* Scull, 1973).

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One explanation of these phenomena is that increasing the magnitude of reinforcement enhances its discriminative effect, and consequently the performance improves in precision (Di Lollo, Ensminger, and Notterman, 1965; Notterman and Mintz, 1965). This view would seem to be supported by the occurrence, in FI schedules, of longer postreinforcement pauses, since this results in fewer responses without reducing the frequency of reinforcement. The question remains, however, of whether in those schedules where the frequency of reinforcement decreases as a result of longer pauses, the effect of increasing the magnitude would be to shorten the postreinforcement pause, or to increase the running rate, or both.

The present study is mainly concerned with this question, as well as with problems of measurement in research of this kind. Much of the divergence in previous studies is probably due to the measure used, that is, the overall rate of responding, which includes both the postreinforcement pause and the running rate. These may be affected differently by the magnitude of reinforcement, and when they are averaged, the extent of the changes in the two may be masked. The present experiments reveal major effects not reflected fully in the overall rate.

EXPERIMENT 1

This experiment investigated the effects of manipulating the concentration of the reinforcer upon the performance of rats on a conventional FI schedule. The durations of the postreinforcement pauses and the running rates were analyzed separately, as a function of the concentration of the preceding reinforcer.

METHOD

Subjects

Three male albino rats (122, 123, and 124) each with experience on a response-initiated FI schedule, to be described in Experiment 2, were housed individually and maintained at 80% of their free-feeding weights. Water was freely available in the home cages.

Apparatus

The operant-conditioning chambers measured 18.5 cm high, 24.0 cm long, and 20.0 cm wide. The walls were sanded plate aluminum; on one of the 20.0-cm wide walls a lever was mounted, 5.0 cm wide and protruding 1.5 cm into the chamber, operated by a force of approximately 10.0 g (0.10 N). A recess, 4.0 cm wide, 5.0 cm high, and 5.0 cm deep, was located in the center of the panel, 7.0 cm to the right of the lever. The reinforcer, 0.05 ml of a solution of Nestlé's condensed milk in water, was delivered up to the floor of the recess by a motor-operated dipper mechanism. The chamber was housed in a sound-attenuating box, containing a 3-W light located on the ceiling and an exhaust fan, mounted on one side, producing ambient noise at 60 ±2 dB. The scheduling and recording equipment were in a separate room.

To facilitate within-session changes in the concentration of the reinforcer, four containers were mounted on a circular aluminum plate, the center of which was bolted to the spindle of a 24-V ac motor/gearbox. This was situated below the dipper mechanism and the container into which the dipper descended could be changed by operating the motor via external scheduling equipment.

Procedure

The subjects were placed on an FI 60-sec schedule for 40 daily 1-hr sessions before testing. The concentration of the condensed milk was 30% throughout the training phase, but the milk containers were rotated after every six reinforcements so that the animals might habituate to the sound of the motor/gearbox.

Testing

The same schedule was in operation as during training. Four different reinforcer concentrations, 10%, 30%, 50%, 70%, were presented in blocks of six reinforcements; the order of the blocks was random with the constraint that in a session, each block occurred once. Eight test sessions were conducted, each consisting of 24 reinforcements.

RESULTS AND DISCUSSION

Figure 1 shows the effects upon performance of the preceding reinforcer. For all subjects, both the duration of the postreinforcement pause and the running rate increased linearly, as a function of the concentration of the reinforcer. These effects occurred consistently throughout the test sessions (see Ta-

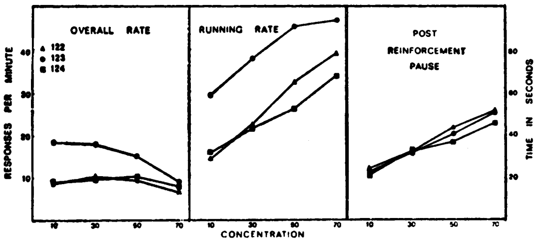

Fig. 1. FI: overall rate (left panel), running rate (center panel), and postreinforcement pause (right panel) as functions of concentration of the preceding reinforcement. Data were averaged across the test sessions for each of the three rats.

ble 1). The duration of the postreinforcement pause changed appropriately after a new concentration was presented in a block, and there was no ordinal effect within any one test block (see Table 2). It was therefore the concentration of the reinforcer initiating an interval that significantly affected the duration of the subsequent postreinforcement pause.

These results are in agreement with those of Staddon (1970), who found that on an FI 60-sec schedule with pigeons, longer reinforcer durations lengthened postreinforcement pauses. Similar depressive effects of the preceding reinforcer duration were observed with rats, on a multiple fixed-interval fixed-interval schedule, by Jensen and Fallon (1973). In Staddon's study, the running rate of pigeons decreased as a function of the duration of the preceding reinforcer; this is in direct contrast to the present results, which show that when the concentration of the reinforcer was increased, the subsequent running rate also increased. This apparent discrepancy is discussed below.

EXPERIMENT 2

On an FI schedule, each interval is usually timed from the preceding reinforcement, and after each interval is completed, the first response is reinforced. On a response-initiated FI (*tand* FR 1 FI) schedule, on the other hand, the interval is initiated by the first response after reinforcement. Chung and Neuringer (1967) and Shull (1970) found that pigeons produce relatively long postreinforcement pauses on this schedule and that these pauses are an increasing function of the FI value. The running time (*i.e.,* time from first response to reinforcement) approximates the FI value, while there is variation in the postreinforcement pause, and consequently in the time between reinforcements.

On a *tand* FR 1 FI schedule, the shorter the postreinforcement pause the sooner the next reinforcement becomes available. If greater

Table 1

Interquartile ranges of the postreinforcement pause durations and of the running rates as a function of the preceding reinforcer concentration. Data are from the test sessions on each schedule.

		FI		tand *FR FI*			*FR*	
Animal	*Concentration*	*Post-Reinforcement Pause in Seconds*	*Running Rate (Responses per Minute)*	*Post-Reinforcement Pause in Seconds*	*Running Rate (Responses per Minute)*	*Animal*	*Post-Reinforcement Pause in Seconds*	*Running Rate (Responses per Minute)*
122	10%	11-31	5-24	14-42	11-19	132	13-20	55-96
	30%	18-44	8-42	23-49	10-23		18-31	66-96
	50%	34-57	21-66	47-90	12-30		24-36	65-90
	70%	45-58	23-90	92-137	14-32		29-44	57-85
123	10%	14-33	14-49	19-50	18-40	133	10-18	101-130
	30%	21-41	26-54	21-65	20-42		12-19	108-132
	50%	31-50	38-80	48-94	22-42		23-35	83-128
	70%	43-60	34-84	74-123	25-43		28-39	72-108
124	10%	13-34	10-22	14-27	11-21	141	8-12	110-147
	30%	25-42	13-30	31-53	12-24		10-14	114-137
	50%	32-43	15-36	45-78	10-24		12-18	115-146
	70%	40-54	22-46	64-136	10-19		15-19	96-134

Table 2

Mean duration of the postreinforcement pause as a function of the ordinal position in a block. Data are from the test sessions on each schedule.

		Ordinal Position																		
		FI						tand *FR FI*							*FR*					
Concen-tration	*Animal*	1	2	3	4	5	6	1	2	3	4	5	6	*Animal*	1	2	3	4	5	6
10%	122	21.5	17.8	25.9	13.6	27.8	21.4	34.4	23.8	32.4	23.1	38.3	26.3	132	16.4	13.3	17.1	14.0	17.7	26.6
	123	21.4	18.5	21.1	13.5	26.6	36.0	23.5	22.0	24.9	25.8	35.9	62.1	133	13.6	12.0	19.0	14.8	15.2	14.5
	124	30.6	16.3	18.0	21.4	25.3	34.4	21.8	13.4	19.1	23.1	18.1	32.1	141	8.9	9.4	9.7	9.9	10.9	10.8
	Mean	24.5	17.5	21.7	16.2	26.6	30.6	26.6	19.7	25.5	24.0	30.8	40.2		13.0	11.6	15.3	12.9	14.6	17.3
30%	122	32.5	20.9	39.6	33.3	35.4	32.0	31.0	37.1	43.3	32.3	35.3	38.8	132	22.9	21.6	23.5	26.6	22.0	35.9
	123	34.4	37.6	28.3	25.4	27.9	37.4	44.9	43.1	31.5	39.1	51.1	58.4	133	14.6	18.7	27.4	20.3	27.6	22.0
	124	29.6	32.1	34.8	27.9	41.8	30.3	41.5	41.0	40.3	36.3	48.3	43.1	141	12.3	10.1	11.5	11.6	15.4	12.8
	Mean	32.2	30.2	34.2	28.9	35.0	33.2	39.1	40.4	38.4	35.9	44.9	46.8		16.6	16.8	20.8	19.5	21.7	23.6
50%	122	37.3	44.0	42.6	42.6	47.5	46.5	66.3	52.3	79.9	69.1	86.5	65.3	132	36.6	32.3	32.5	28.4	23.3	46.1
	123	34.1	39.3	39.9	42.3	43.9	44.5	64.5	63.8	73.3	67.8	73.9	71.8	133	28.1	34.9	31.0	33.1	28.1	28.6
	124	37.4	35.9	32.1	40.6	33.3	42.4	58.0	56.6	62.5	58.6	64.4	68.0	141	16.9	14.0	14.4	15.3	14.7	13.2
	Mean	36.3	39.7	38.2	41.8	41.6	44.5	62.9	57.6	71.9	65.2	74.9	68.4		27.2	27.1	26.0	25.6	22.0	29.3
70%	122	54.6	51.0	53.9	50.1	51.9	49.5	96.6	114.9	120.5	104.1	111.8	110.9	132	44.5	35.8	37.8	35.2	41.5	27.6
	123	48.3	48.3	51.6	43.5	54.6	58.6	87.0	104.6	104.5	102.6	120.5	90.0	133	43.9	30.1	39.1	28.8	34.1	37.9
	124	42.4	49.6	45.9	46.8	46.2	45.1	105.4	92.3	109.8	108.4	93.6	106.9	141	18.7	17.3	15.1	17.7	15.4	16.4
	Mean	48.4	49.6	50.5	46.8	50.9	51.1	96.3	103.9	111.6	105.0	108.6	102.6		35.7	27.7	30.7	27.2	30.3	27.3

magnitude of reinforcement enhances the accuracy of performance (*cf.* Notterman and Mintz, 1965), an inverse relationship would be expected between the concentration of the reinforcer and the duration of the postreinforcement pause on this schedule; if, however, the aftereffect of the reinforcer is inhibitory, higher concentrations should be followed by longer postreinforcement pauses. This was investigated in the present experiment.

Method

Three naive male albino rats (122, 123, and 124), were housed and maintained as described in Experiment 1. The apparatus was also the same.

Procedure

The lever-pressing responses were shaped, and after 30 reinforcements on FR 1, the subjects were placed on a *tand* FR 1 FI 60-sec schedule. Testing began after 50 daily 1-hr sessions. The concentration of the condensed milk was 30% throughout the training phase.

Testing

Eight test sessions were conducted in the same manner as in Experiment 1.

Results and Discussion

Figure 2 shows that the postreinforcement pauses increased markedly as the concentration of the reinforcer was increased. The running rate, for Subject 122, increased at 50% and 70% (and slightly at 30%); for Subject 123, it increased at 30% and 50% but declined at 70%; for Subject 124, it increased at 30% and declined at 50% and 70% (see Tables 1 and 2). It was evident that the systematic but small changes in the overall rates reflected mainly the effect upon the durations of the postreinforcement pauses. Although the postreinforcement pause delays the next reinforcement, higher concentrations were followed by remarkably long postreinforcement pauses, twice as long as those observed in the comparable FI schedule of Experiment 1. Consequently, the reinforcement rates declined well below the maximum possible.

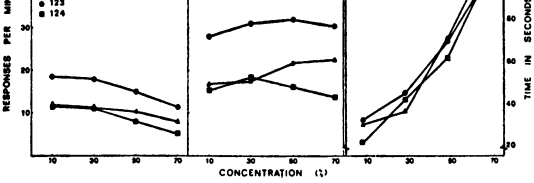

Fig. 2. *Tand* FR 1 FI: overall rate (left panel), running rate (center panel), and postreinforcement pause (right panel) as functions of concentration of the preceding reinforcement. Data were averaged across the test sessions for the three rats.

These results indicate that when the magnitude of reinforcement is increased, the aftereffect that is enhanced is inhibitory.

EXPERIMENT 3

Fixed-interval and *tand* FR 1 FI schedules specifically involve temporal contingencies; the minimum interreinforcement time is fixed in the former, and in addition the running time is fixed in the latter. On an FR schedule, however, there is no explicitly arranged temporal contingency, and both the interreinforcement time and the running rate vary as consequences of the subject's behavior. As in *tand* FR 1 FI, the interreinforcement interval is increased by longer postreinforcement pauses.

Method

Subjects

Three naive male white rats (132, 133, and 141) were housed individually and maintained at 80% of their free-feeding weights. Water was freely available in the home cages.

Apparatus

The apparatus was the same as in the previous experiments.

Procedure

After the lever-pressing responses were shaped, the subjects were placed on an FR 30 schedule for 50 daily 1-hr sessions. Eight test sessions were then conducted, in the same way as in the previous experiments.

Results and Discussion

Figure 3 shows that the duration of the postreinforcement pause was an increasing linear function of the concentration of the preceding reinforcer. As in the previous experiments, this effect was consistent over sessions, and within each block of a given concentration

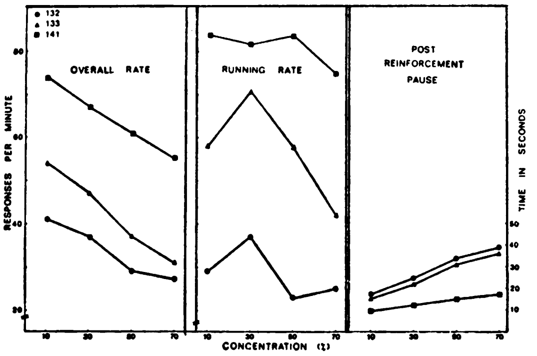

Fig. 3. FR: overall rate (left panel), running rate (center panel), and postreinforcement pause (right panel) as functions of concentration of the preceding reinforcement. Data were averaged across the test sessions for the three rats.

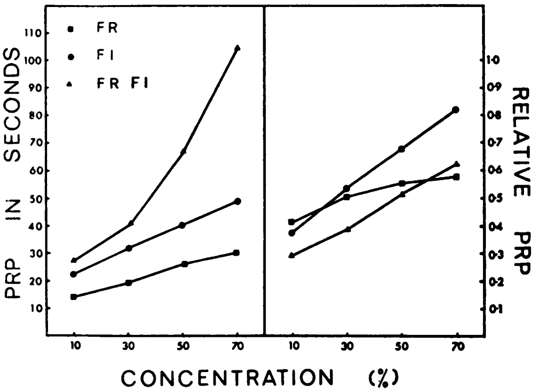

Fig. 4. Postreinforcement pause (left panel) and postreinforcement pause proportional to the interreinforcement interval (right panel) as functions of reinforcement concentration. Data were averaged across the test sessions for the three rats on each schedule.

(see Tables 1 and 2). The overall rates declined with increased concentration; although the running rates showed considerable variation, these tended to decline with higher concentrations. On this schedule, as well as on *tand* FR 1 FI 60, the behavioral effect of increasing the concentration of the reinforcer, *i.e.*, the longer postreinforcement pauses and lower overall response rate, resulted in a lower rate of reinforcement.

These results are consistent with those of Hurwitz *et al.* (1965), who found that rats responded at a lower overall rate when their responses were reinforced by a 32% sucrose solution than when reinforced by an 8% solution; they did not record the duration of the postreinforcement pauses or the running rate. However, Powell (1969) found that the postreinforcement pause on FR was inversely related to magnitude. He presented two different durations of the reinforcer, each in the presence of a different stimulus; the control by the accompanying stimuli may have overridden the inhibitory effects of longer durations of reinforcement. Powell's results also differ from Staddon's (1970) finding, also with duration of reinforcer but on an FI schedule, that the postreinforcement pause increased as a function of the duration of the preceding reinforcer.

GENERAL RESULTS

In Figure 4, the mean postreinforcement pause duration is shown as a function of the reinforcer concentration, on the three schedules. The results were different in the three experiments in terms both of the duration of the postreinforcement pauses and of the rates at which each function changed. The functions of the FI and FR schedules were approximately linear, while that for *tand* FR 1 FI was positively accelerated. When, however, the proportional postreinforcement pause, that is, the duration of the postreinforcement pause relative to the duration of the interreinforcement interval was considered (*cf.* Staddon, 1972), the shapes of the functions did not differ greatly; these were approximately linear in all three schedules.

The left panel of Figure 5 shows the mean running rates as a function of the duration of the preceding postreinforcement pause, in

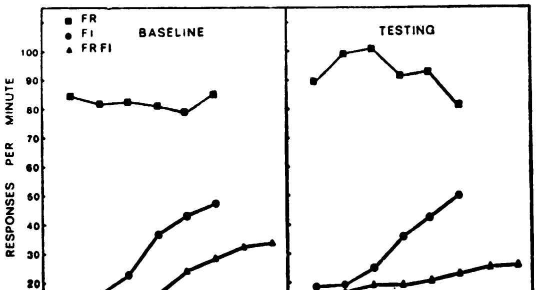

Fig. 5. Running rate as a function of duration of the preceding postreinforcement pause, averaged over the last two training sessions (left panel), and averaged over testing sessions (right panel), across the three rats on each schedule.

the final three days of training, in all three experiments (*i.e.,* at 30% concentration). (The FR data were taken only from Animals 132 and 133; due to an oversight, the running rate was not recorded for Animal 141 during the training sessions). The running rate was found to be an increasing function of the postreinforcement pause, not only on the FI schedule but also, to a lesser extent, on the *tand* FR 1 FI schedule; the function for the FR schedule was flat. Similar relationships were also found between the running rate and the duration of the preceding postreinforcement pause in the test sessions, regardless of concentration (see right panel of Figure 5).

In the two interval schedules, the running rates increased as a function of the concentration of the preceding reinforcer. Although this might be explained with reference to an energizing effect of reinforcement, enhanced when the concentration was increased, it seems equally likely that the increases in the running rate might have been the consequence of longer postreinforcement pauses produced, in turn, by higher reinforcer concentrations. The latter suggestion is strongly supported by the mean running-rate functions for the two interval schedules. These indicate that the response rate in any one interval is related to the temporal point in that interval when responding commences; the longer the pause, the further the point of time in the interval and the higher the subsequent response rate. This evidence suggests that the determinants of the response rate are temporal, rather than motivational, factors.

GENERAL DISCUSSION

Postreinforcement Pause

Jensen and Fallon (1973) and Staddon (1970) reported a positive relationship between the duration of the postreinforcement pause and the preceding reinforcer duration on FI schedules. In Experiment 1 of the present study, a similar relationship was observed when the concentration of the milk reinforcer was manipulated on an FI schedule. The results of Experiments 2 and 3 extend these findings to schedules where, unlike the conventional FI schedule, an increase in the duration of the postreinforcement pause reduces the rate of reinforcement. In both the *tand* FR 1 FI and FR schedules, the inhibiting aftereffects of reinforcement persisted despite the consequent delays in reinforcement.

The slope of the pause/concentration function was determined by the schedule in operation. It was positively accelerated on the *tand* FR 1 FI schedule with very long postreinforcement pauses, while on the FI and FR schedules, the slopes were linear. However, when the postreinforcement pauses were plotted in relation to interreinforcement intervals (Figure 4), the functions on all three schedules became linear, suggesting that the duration of the interreinforcement interval was a factor common to all three schedules, in determining the duration of the postreinforcement pause (*cf.* Killeen, 1969; Neuringer and Schneider, 1968; Staddon, 1972). Ferster and Skinner (1957) indicated that a reinforcing stimulus may acquire inhibitory aftereffects when it signals a period in which reinforcement is not available. In the present case, this inhibitory or S^{Δ} function of the reinforcing stimulus was enhanced by increasing reinforcement magnitude; decreasing the magnitude had the reverse effect.

Running Rate

On the FI schedule, the running rate increased when it was preceded by an increase in both the concentration of the reinforcer and the duration of the postreinforcement pause. The question of which of the latter changes affected the running ratê directly is answered partly by the finding that when during training the reinforcer concentration was held constant, the running rate was nevertheless an increasing function of the length of the preceding postreinforcement pause. This suggests that the running rate is affected directly by the duration of the postreinforcement pause, but that the effect of the concentration of the preceding reinforcer is indirect, mediated through the postreinforcement pause. If this were so, it would be expected that in those cases where the running rate is not positively related to the preceding postreinforcement pause duration, a positive relationship with the preceding reinforcement magnitude should be absent also.

Overall Rate

If in the present case the overall rate were the only measure of behavior, several aspects of the behavioral effects of reinforcement magnitude would have been overlooked. For example, on the FI schedule studied, reinforcer concentration had almost no effect on the overall rates of two of three animals, whereas both the postreinforcement pause and the running rate changed considerably.

In many previous experiments, the magnitude of reinforcement was manipulated during acquisition, before the establishment of stable performance (Collier and Myers, 1961; Collier and Willis, 1961; Guttman, 1953; Hutt, 1954). In these studies, increases were reported in the overall rates of responding as a function of reinforcement magnitude. The present results, obtained after exposure to the schedules for 40 to 50 sessions, extend but do not contradict the earlier findings, since the inhibitory aftereffects of reinforcement develop as behavior stabilizes on a given schedule (*cf.* Ferster and Skinner, 1957).

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