

## AFTEREFFECTS OF REINFORCEMENT ON VARIABLE-RATIO SCHEDULES<sup>1</sup>

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On each of variable-ratio 10, 40, and 80 schedules of reinforcement, when rats' lever-pressing rates were stable, the concentration of a liquid reinforcer was varied within sessions. The duration of the postreinforcement pause was an increasing function of the reinforcer concentration, this effect being more marked the higher the schedule parameter. The running rate, calculated by excluding the postreinforcement pause, was unaffected by concentration. The duration of the postreinforcement pause increased with the schedule parameter, but the proportion of the interreinforcement interval taken up by the pause decreased. Consequently, the overall response rate was an increasing function of the schedule parameter; *i.e.*, it was inversely related to reinforcement frequency, contrary to the law of effect. The running rate, however, decreased with the reinforcement frequency, in accord with the law of effect. When 50% of reinforcements were randomly omitted, the postomission pause was shorter than the postreinforcement pause, but the running rate of responses was not affected.

*Key words:* reinforcement magnitude, postreinforcement pause, running rate, reinforcement omission, law of effect, variable ratio, rats

It is an almost universal phenomenon that the presentation of a reinforcing stimulus is followed by a pause in responding. Given that the reinforcer is a food substance this is not surprising, since for a period after reinforcement the subject is occupied in consummatory activity. In many schedules, however, the postreinforcement pause is longer than the time taken to consume the reinforcer. Moreover, on several schedules of reinforcement, the duration of the postreinforcement pause is affected by variables other than time taken to eat. For example, on a fixed-interval (FI) schedule, it is an increasing function of the duration of the fixed interval (Schneider, 1969; Sherman, 1959), and of the concentration of a liquid reinforcer when the amount is held constant (Lowe, Davey, and Harzem, 1974).

One explanation of this phenomenon is that the reinforcer functions as a discriminative stimulus, signalling the start of a period in which reinforcement is not available (Ferster

and Skinner, 1957; Skinner, 1938). However, even on schedules where the postreinforcement pause delays the availability of the next reinforcement, for example fixed-ratio (FR) and response-initiated fixed-interval (*tand* FR 1 FI) schedules, increasing the magnitude of reinforcement has been shown to increase the duration of the postreinforcement pause (Lowe *et al.*, 1974). It appears, therefore, that the reinforcing stimulus has an inhibiting aftereffect irrespective of any reduction that may occur in reinforcement frequency. This is further supported by the finding that, on an FI schedule, when some of the arranged reinforcements are omitted but at each omission the stimuli accompanying the reinforcer continue to be presented, the poststimulus pauses are considerably shorter than the postreinforcement pauses (Kello, 1972; Staddon and Innis, 1966; 1969).

The generality of the inhibitory aftereffect of reinforcement has not yet been investigated. For example, a stringent test of the phenomenon would be to see if it also occurs on a schedule that generates relatively brief postreinforcement pauses, and high response rates. On the basis of these considerations, the present study investigated the effects of reinforcement magnitude and of reinforcement omis-

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sion on responding on variable-ratio (VR) schedules (Ferster and Skinner, 1957).

### EXPERIMENT I: MANIPULATION OF SCHEDULE PARAMETER AND REINFORCER MAGNITUDE

#### METHOD

##### *Subjects*

Four naive male hooded rats, 120 days old at the start of the experiment, were individually housed and maintained at 80% of their free-feeding weights. Water was freely available in the home cages.

##### *Apparatus*

The operant-conditioning boxes 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 box, operated by a force of approximately 15.0 g (0.15 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. The dipper remained in the up position, and operated at each reinforcement, the dipping action taking approximately 0.8 sec. (Under these conditions the time taken to consume the reinforcer on a continuous reinforcement schedule does not exceed 3 sec; Lowe, 1974.) The box was housed in a sound-attenuating outer chamber, containing a 3-W light located on the ceiling and an exhaust fan, mounted on one side, producing ambient noise at  $60 \pm 2$  dB. The house-light remained on throughout the experiment. The scheduling and recording equipment were in a separate room.

To facilitate within-session changes in the concentration of the reinforcer, a circular dish divided into six compartments was 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, and the container into which the dipper descended could be changed by operating the motor via external scheduling equipment. Data were collected and analyzed using a Data General Nova 1200 computer.

##### *Procedure*

Lever-pressing responses were shaped in the first session. In the next session, the animals were placed on a VR-80 schedule in daily sessions, including weekends. The sequence of VR requirements is shown in Table 1. Each session lasted until 77 reinforcements occurred. The sessions continued until both of the following stability criteria were met: (i) when a minimum of 30 sessions had been conducted, and (ii) when the response rate in any one of five consecutive sessions did not differ by more than 10% from the mean rate for those sessions. During training, the concentration of the reinforcer was 30%.

When the response rate was stable, four test sessions were conducted. In each session, the following reinforcer concentrations were presented in random order, with the constraint that the same concentration did not occur consecutively more than three times: 10%, 30%, 50%, and 70%. This procedure was then repeated on VR 10 and VR 40 in that order, the test sessions being conducted after the establishment of stable responding (see Table 1). On each schedule parameter, the response rate became stable within approximately 35 sessions.

#### RESULTS

Figure 1 shows the median duration of the postreinforcement pause, the running rate, and the overall rate in the baseline sessions, and as functions of the concentration of the preceding reinforcer, in the test sessions. (See Table 2 for the interquartile ranges in the test sessions.) The running rate was calculated after excluding the postreinforcement pauses. For each subject and on every schedule parameter, duration of the postreinforcement pause was an increasing function of reinforcer magnitude. On VR 10 and VR 40, the durations were almost the same for all subjects, but on VR 80 there was more between-subject difference. The heights of the functions increased as a function of schedule parameter; *i.e.*, for any one concentration, duration of the postreinforcement pause was directly related to the schedule parameter. Moreover, the higher the schedule value, the steeper were the functions; *i.e.*, the differences between the effects of the concentrations were also directly related to schedule parameter.

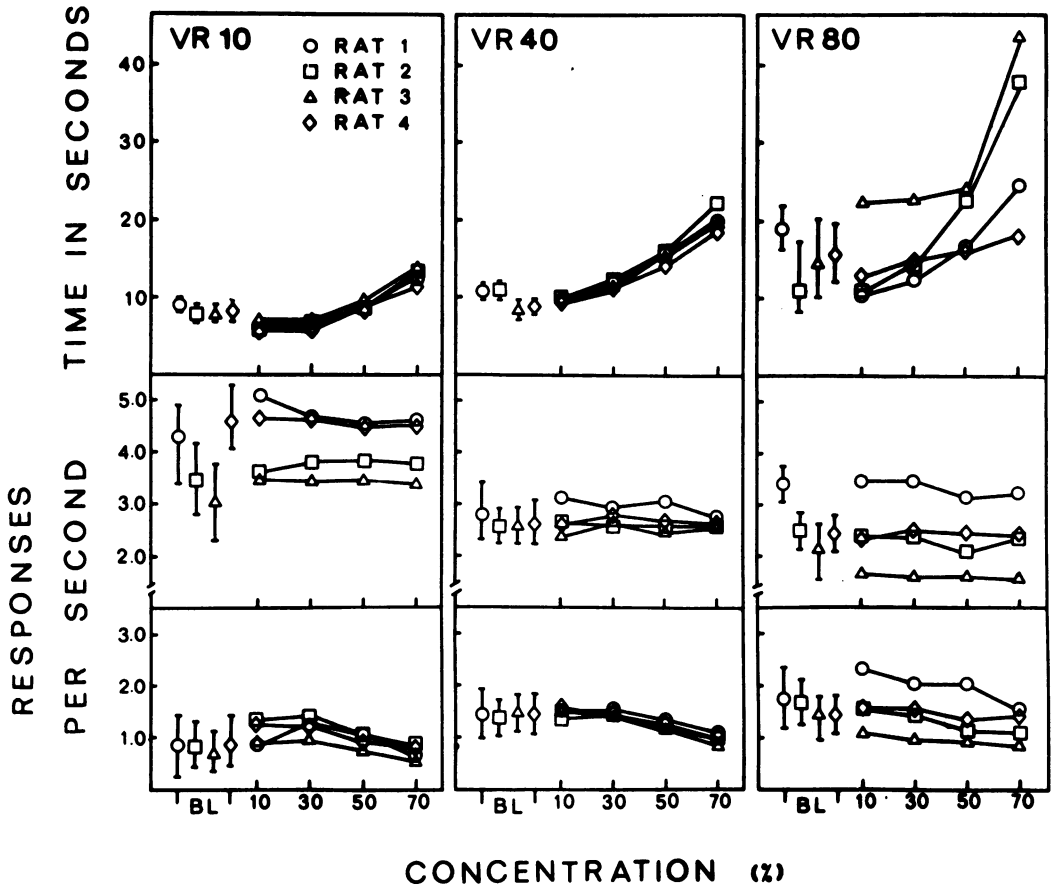


Fig. 1. Median duration of postreinforcement pause (upper section), running rate (middle section), and overall rate (lower section) on the last three baseline (BL) sessions, and as functions of the concentration of reinforcer on the test sessions. Interquartile ranges are also shown for the baseline sessions.

For each subject at a given schedule value, the running rate of responses remained approximately the same on all reinforcer concentrations. There was, however, an inverse relationship between the schedule parameter

and the running rate: the height of the running-rate functions decreased as the variable ratio increased (except for Subject 1 on VR 80). The overall response rates declined as a function of reinforcer magnitude. This de-

Table 1  
The Sequence of Variable-Ratio Requirements Used in Each Schedule

Schedule	Sequence of Ratios (left to right)									
VR 10	16	1	10	14	7	12	2	8	13	4
	10	7	8	19	16	3	11	5	9	14
	18	4	18	5	9	17	15	6	15	19
	4	1	2	6	11	13	12	17		
VR 40	64	4	40	56	28	48	8	32	52	12
	40	28	32	76	64	12	44	20	36	56
	72	16	72	20	36	68	60	24	60	76
	16	4	8	24	44	52	48	68		
VR 80	128	8	80	112	56	96	16	64	104	24
	80	56	64	152	128	24	88	40	72	112
	144	32	144	40	72	136	120	48	120	152
	32	8	16	48	88	104	96	136		

Table 2

The interquartile ranges of the duration of postreinforcement pauses, the running rate, and the overall rate of responses, following each reinforcer concentration on each schedule.

Concentration (%)	Postreinforcement Pause in Seconds			Running Rate (responses per second)			Overall Rate (responses per second)		
	VR 10	VR 40	VR 80	VR 10	VR 40	VR 80	VR 10	VR 40	VR 80
<b>ANIMAL 1</b>									
10	3.9- 7.4	8.2-11.8	8.8-13.4	3.69-6.35	2.41-3.62	2.98-3.91	0.75-1.82	1.10-1.88	1.70-2.75
30	4.6- 7.4	10.2-13.7	10.3-15.8	3.69-5.58	2.41-3.51	2.89-3.76	1.01-1.82	1.03-1.97	1.39-2.53
50	6.9-10.0	12.5-19.7	14.3-21.2	3.75-5.50	2.38-3.59	2.53-3.63	0.53-1.53	0.85-1.73	1.33-2.49
70	9.5-13.5	14.4-27.2	20.3-29.1	3.44-5.04	2.11-3.44	2.66-3.68	0.41-1.37	0.54-1.55	1.08-2.00
<b>ANIMAL 2</b>									
10	5.1- 8.4	8.8-11.3	8.7-17.3	3.05-4.29	2.33-3.19	2.05-2.72	0.42-1.42	1.12-1.84	1.08-1.88
30	5.5- 8.0	10.4-13.7	12.2-19.6	3.33-4.51	2.21-2.99	2.05-2.72	0.75-1.64	1.04-1.75	1.02-1.80
50	6.8- 9.9	13.0-21.4	18.2-33.9	3.12-4.55	2.11-3.02	1.45-2.58	0.53-1.53	0.63-1.59	0.56-1.58
70	9.7-17.8	19.2-27.8	30.7-59.0	3.24-4.48	2.18-2.99	1.92-2.77	0.32-0.97	0.49-1.49	0.54-1.55
<b>ANIMAL 3</b>									
10	5.6-10.0	8.2-11.1	14.4-29.9	2.86-4.07	2.05-2.88	1.27-2.11	0.44-1.42	1.02-1.73	0.53-1.53
30	6.1- 7.6	9.9-13.6	16.8-31.6	2.75-3.95	2.24-3.00	1.26-1.95	0.47-1.46	1.01-1.79	0.46-1.46
50	8.1-11.6	12.8-19.3	16.6-37.6	2.72-4.12	2.10-2.81	1.24-1.98	0.36-1.19	0.72-1.63	0.44-1.43
70	12.0-15.5	18.0-26.5	32.6-53.8	2.62-3.95	2.15-3.09	1.21-1.93	0.27-0.80	0.42-1.42	0.36-1.19
<b>ANIMAL 4</b>									
10	4.9- 7.8	8.3-11.4	10.4-17.8	4.13-5.63	2.22-3.06	1.95-2.69	0.68-1.65	1.17-1.87	1.22-1.87
30	4.9- 8.2	9.4-13.1	12.6-19.4	4.01-5.36	2.35-3.47	2.21-2.79	0.66-1.28	1.01-1.83	1.15-1.91
50	7.1-11.3	11.7-17.2	14.3-21.3	4.06-5.40	2.23-3.33	2.24-2.82	0.44-1.44	0.71-1.66	0.80-1.75
70	8.2-14.3	16.4-21.8	16.3-25.4	4.16-5.30	2.25-2.97	2.08-2.79	0.39-1.32	0.49-1.49	1.03-1.78

cline was a reflection of the increase in duration of the postreinforcement pauses, since the running rates were not affected by reinforcer magnitude.

In the baseline sessions, the median duration of the postreinforcement pause was an increasing function of the variable ratio (except for Subject 2 on VR 80). The running rate was inversely related to the schedule parameter, again with the exception of one data point (Subject 1 on VR 80). The overall response rates, however, increased with increases in the variable ratio. At first sight, these data appear contradictory, since an increase in duration of the postreinforcement pause, combined with a decrease in running rate, might be expected to result in a decrease in overall rate. However, although duration of the postreinforcement pause increased, the proportion of the mean interreinforcement interval occupied by the postreinforcement pause decreased (see left panel of Figure 2); that is, a greater proportion of the interreinforcement interval (and, of course, of the total session time) was taken up in responding. This resulted, therefore, in an increase in the overall response rate. This was despite the fact that

running rates declined; *i.e.*, the changes in postreinforcement pauses contributed more to the overall rate than did the changes in the running rates.

The right panel of Figure 2 shows, for each animal, that duration of the postreinforcement pause relative to the interreinforcement interval, was an inverse function of the schedule parameter. Moreover, in almost every case, the higher the concentration, the higher were the functions: the relative duration of the postreinforcement pause was positively related to the concentration of the reinforcer.

## EXPERIMENT II:

### OMISSION OF REINFORCEMENT

Further evidence for the inhibitory after-effects of reinforcement magnitude has been provided by studies using a reinforcement omission procedure. When, on the FI schedule, the reinforcer was omitted, the subsequent pause was shorter than the postreinforcement pause (Kello, 1972; Staddon and Innis, 1966, 1969). The present experiment investigated the effects of reinforcement omission on performance on the VR-40 schedule.

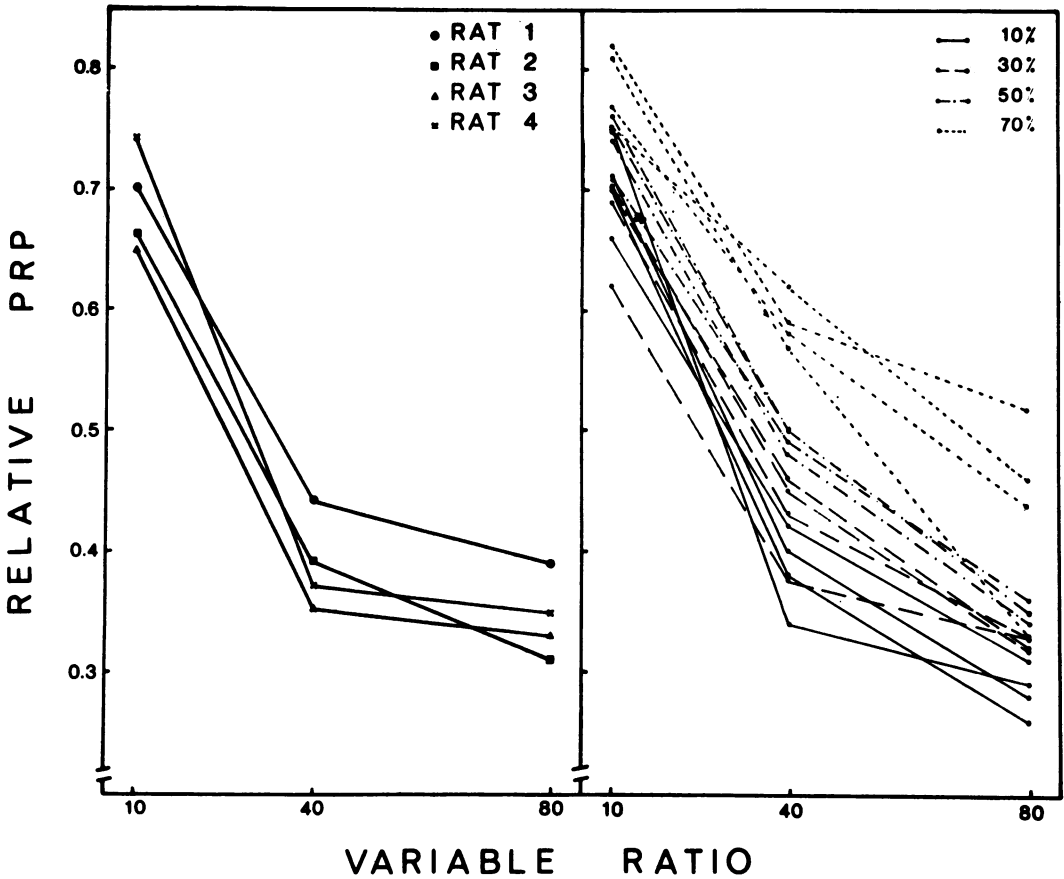


Fig. 2. Duration of the postreinforcement pause as a proportion of the mean interreinforcement interval, shown as a function of the schedule parameter (left panel). Right panel shows separately for each subject and for each concentration, the proportional duration of the postreinforcement pause as a function of the schedule parameter.

METHOD

Subjects

The same rats as in Experiment I served and were maintained as before.

Apparatus

The apparatus was the same as in Experiment I. In addition, a frequency generator and amplifier were used to produce a tone (1000 Hz) through a 15-ohm speaker located on the lid of the experimental box. The intensity of the tone was  $85 \pm 2$  dB (reference level: 0.0002 dyn/cm at 1000 Hz). A 12-W 24-V bulb located 6.0 cm above the lever produced the light stimulus.

Procedure

After completion of Experiment I, the animals were placed on VR 40, with each rein-

forcement accompanied by a light + tone stimulus lasting 2 sec. The concentration of the reinforcer was 30% throughout this experiment. Each daily session lasted until 77 reinforcements occurred. When the response rate became stable according to the criteria described in Experiment I, the reinforcer was omitted randomly on 50% of the occasions and only the light + tone was presented. The procedure was carried out for four consecutive sessions, followed by four further sessions in which presentation of the reinforcer was restored to 100%.

RESULTS

Figure 3 shows, for each animal, the mean duration of the postreinforcement pause (see Table 3 for interquartile ranges) and the running rate of responses following reinforcement and following omission. In all cases, duration

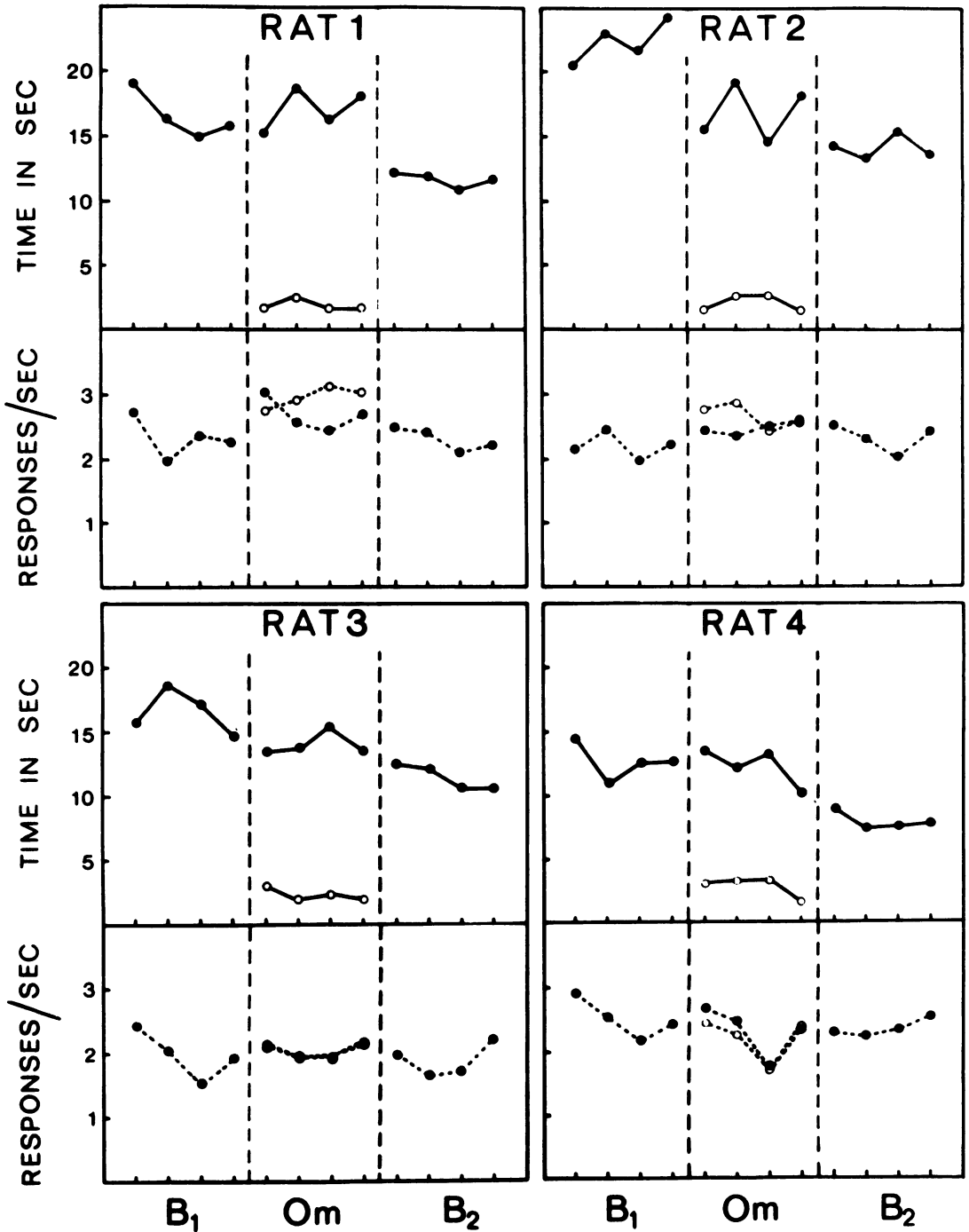


Fig. 3. For each subject, the duration of the postreinforcement pause (upper sections) and the running rate (lower sections) in successive sessions before testing (B<sub>1</sub>), during reinforcement omission (Om), and on returning to baseline (B<sub>2</sub>), *i.e.*, when reinforcement was returned to 100%. Closed circles are the postreinforcement data, and open circles the postomission data.

Table 3

The overall response rates, and interquartile ranges of durations of pauses following reinforcement in the baseline, test, and return-to-baseline sessions, and following omission of reinforcement in the test sessions.

Animal	Response Rate (response/second)				Postreinforcement Pause (seconds)				
	Baseline	Test		Baseline	Baseline	Test		Baseline	
		Following:				Following:			
		S <sup>R</sup>	Omission			S <sup>R</sup>	Omission		
1	1.17	1.21	2.58	1.42	13.9-17.1	15.8-19.0	0.7-2.1	11.5-14.3	
2	0.94	1.19	2.30	1.28	16.0-20.3	14.6-18.4	0.9-3.2	12.9-15.8	
3	1.05	1.12	1.81	1.24	13.2-17.5	13.0-15.5	0.8-2.9	10.3-13.0	
4	1.35	1.37	1.87	1.61	10.1-13.5	11.0-13.6	0.9-3.3	7.5- 9.6	

of the pause was shorter after omission than after reinforcement. For Animals 2, 3, and 4 the postreinforcement pauses somewhat declined in the omission and the return-to-baseline sessions.

There was no systematic difference in the running rates after omission and reinforcement, and the running rates remained approximately the same in the baseline, omission, and return-to-baseline sessions.

In every case, the overall response rate was higher following omission than it was following reinforcement. The fact that reinforcement was omitted on some occasions did not affect the rate at which responses occurred following reinforcement; *i.e.*, the overall response rate following reinforcement in test sessions was approximately the same as the overall response rate in baseline sessions.

## DISCUSSION

These results show that on VR schedules, the postreinforcement pause varies as a direct function of the reinforcer magnitude. This is consistent with previous findings of the same relationship on the FI schedule (Jensen and Fallon, 1973; Lowe *et al.* 1974; Staddon, 1970), and on *tand* FR 1 FI, and FR schedules (Lowe *et al.*, 1974). Moreover, the extent to which responding ceased after reinforcement was related also to the schedule parameter, indicating that the effect of the reinforcer magnitude was not absolute, but relative to the baseline postreinforcement pause produced by a given schedule. The changes in durations of the postreinforcement pauses were remarkably orderly, despite the fact that on VR schedules the postreinforcement pause is short, as it was in the present study, and that the differences in dura-

tions of pauses between one experimental condition and the next was in the order of a few seconds.

Farmer and Schoenfeld (1967) reported that on random-ratio schedules, the duration of the postreinforcement pause was directly related to the schedule value. The present results, for the VR schedules, are in agreement with this finding. However, in Farmer and Schoenfeld's (1967) experiment, the running rate was not affected by the size of the random ratio, whereas in the present study, the running rate declined as a function of the schedule parameter. It is possible that this difference may be due to the different way in which reinforcement probabilities are generated on VR and random-ratio schedules.

When some of the reinforcements were omitted, the pause on the occasion of omission was very brief, and it was shorter than the postreinforcement pause. This is in agreement with previous studies of reinforcement omission on FI schedules (Kello, 1972; Staddon and Innis, 1966; 1969) and on FR schedules (McMillan, 1971).

The inverse relationship between the overall response rate and the schedule parameter has been also observed on random-ratio schedules (Brandauer, 1958; Kelly, 1974). These functions would appear not to be consistent with the Law of Effect (Herrnstein, 1961; 1970), as the Law would predict a direct and not an inverse relationship between response rate and rate of reinforcement, as determined by the schedule parameter. In situations such as the present one, however, the overall rate is not the best measure of responding (*cf.* Lowe *et al.*, 1974). The results of Experiment I revealed that changes in running rate and the duration of the postreinforcement pause inter-

act in complex ways in determining the overall response rate. For example, the overall rate may increase despite the fact that both the running rate and the postreinforcement pause may decrease. In the present case, the Law of Effect holds when the running rate, and not the overall rate, is taken into account. In view of the complex effects that are found to operate on the postreinforcement pause, a measure that excludes the postreinforcement pauses, *i.e.*, the measure of running rate, would probably be found to reflect more accurately the relationship described by the Law of Effect.

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