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INHIBITING FUNCTION OF REINFORCEMENT: MAGNITUDE EFFECTS ON VARIABLE-INTERVAL SCHEDULES[1]

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In two experiments, the performance of rats under constant-probability and arithmetic variable-interval schedules respectively was compared when the concentration of a liquid reinforcer was varied within sessions; in other sessions, half of the reinforcers were randomly omitted. When the discriminative function of the reinforcer as a signal for a decrease in the probability of reinforcement was attenuated (the constant-probability schedule) the postreinforcement pause duration was nevertheless an increasing function of reinforcer magnitude. This relationship was also present, but more marked, when the temporal discriminative function of the reinforcer was enhanced (the arithmetic schedule). These results suggested that reinforcement has an unconditioned suppressive effect on the reinforced response distinct from any discriminative function it may acquire. The reinforcement-omission effect, where response rate accelerates following omission, was observed when the reinforcer functioned as an effective temporal discriminative stimulus, but not when such temporal control was absent.

Key words: inhibition, discriminative control, postreinforcement pause, constant probability variable interval, arithmetic variable interval, rats

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There is strong evidence that under many schedules of reinforcement, the reinforcer functions as a discriminative stimulus. Under the fixed-interval (FI) schedule, for example, reinforcement signals a period in which the next reinforcement is not available, thereby setting the occasion for not responding and resulting in the relatively long postreinforcement pauses that typically occur under that schedule (Ferster and Skinner, 1957; Skinner, 1938). It is interesting to note that this kind of discriminative control is observed even under those schedules where each pause delays the next reinforcement; for example under fixed-ratio (FR) and response-initiated FI (tandem FR 1 FI) schedules (Ferster and Skinner, 1957; Shull 1970). Consequently, under these schedules the frequency of reinforcement is considerably lower than the maximum possible. Further, when the magnitude of the reinforcer is varied within sessions, the duration of the postreinforcement pause is found to be an increasing function of the preceding reinforcer magnitude. Reports from this laboratory have shown that under FI, FR, tandem FR 1 FI, interresponse time ($IRT > t$), and variable-ratio (VR) schedules, the duration of the postreinforcement pause is a positive function of the concentration of a liquid reinforcer, with the volume of that reinforcer being held constant (Lowe, Davey, and Harzem, 1974, 1976; Priddle-Higson, Lowe, and Harzem, 1976). Moreover, under an FI schedule where the beginning of an interval (*i.e.,* of a period of nonavailability of reinforcement) is occasionally signalled not by the reinforcer but by another stimulus presented in lieu of it, the subsequent poststimulus pauses are shorter than the pauses following the reinforcer itself (Kello, 1972; Staddon and Innis, 1966, 1969; Zeiler, 1972). Although it may be possible to explain these relationships in terms of the discriminative function of reinforcement (*cf.* Staddon, 1972), these data suggest that the reinforcer may function in yet another way. A reinforcing stimulus may have a suppressive effect on responding as distinct from any discriminative control, *i.e.,* regardless of whether or not the reinforcer signals a period of nonreinforcement. For a time after its presentation, the reinforcer may occasion behavior

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that competes or interferes with the reinforced response, the duration of the resulting response-suppression being related to the magnitude of the reinforcer.

One way of testing this possibility would be to study the aftereffects of reinforcement under a schedule where the probability of reinforcement remains constant at all times. Under such a schedule, the presentation of a reinforcer would not provide discriminative control with respect to when the next reinforcer was to be delivered, *i.e.,* it should be free of temporal discriminative properties (Staddon, 1972; 1975). A schedule that has this characteristic is the constant-probability variable-interval (VI) schedule (Catania and Reynolds, 1968; Fleshler and Hoffman, 1962). Would the postreinforcement pause under this schedule vary in an orderly fashion in relation to changes in reinforcer magnitude (concentration) and omission of reinforcement? Also, how would such changes affect responding in the remainder of the interreinforcement interval? These questions were investigated in the first experiment.

EXPERIMENT I: CONSTANT PROBABILITY VI SCHEDULE

METHOD

Subjects

Three naive male hooded rats, 90 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 cm long, and 20 cm wide. The walls were sanded aluminum plate. On one of the 20-cm wide walls, a 5-cm wide lever was mounted, protruding 1.5 cm into the box and operated by a force of approximately 0.15 N. A recess, 4 cm wide, 5 cm high and 5 cm deep, was located in the center of the panel 7 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 0.5 sec. The box was housed in a sound-attenuated outer chamber, 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 houselight remained on throughout the experiment. The stimuli accompanying reinforcement in Phase II of the experiment were produced as follows: 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 ± 2 dB (reference level: 0.0002 dyne/cm^2 at 1000 Hz). A 12-W, 24-V bulb located 6 cm above the lever produced the light stimulus. 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 four compartments was mounted on a circular aluminum plate, the center of which was bolted to a 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 on digital and printout counters.

The constant-probability VI schedule was programmed using a device which advanced a loop of punched tape at a constant rate. Holes punched in the tape provided a series of 15 intervals, with a mean duration of 60 sec. The intervals, in seconds, derived from the formula given by Catania and Reynolds (1968), were in order as follows: 36.0, 52.1, 17.9, 139.1, 12.9, 109.1, 43.0, 23.4, 4.0, 52.1, 199.1, 74.1, 29.4, 89.1, and 8.3.

Procedure

Lever-pressing responses were trained in the first session. In the next session, the subjects were placed under the constant-probability VI 60-sec schedule and continued in daily sessions. The first response in each session was reinforced and the VI schedule then operated, beginning at a different place in the series of intervals in each session. At the end of each interval when a response was to be reinforced, the controlling apparatus stopped until the next response occurred; the next interval began at the delivery of reinforcement. Sessions ended after each interval in the series had occurred four times (61 reinforcements). The duration of each session was approximately 1 hr. The sessions continued until responding was stable—*i.e.*, 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, all four compartments of the container were filled with the same concentration of reinforcer (40% solution of Nestlé's condensed milk in water measured by volume), and the container was rotated in the same way as in subsequent test sessions, *i.e.*, after every fifth reinforcement. The numbers of sessions for each animal on the training (baseline) condition are shown in Table 1.

Phase I. Manipulation of reinforcer magnitude. When the response rate was stable, three consecutive test sessions were conducted. In each of these sessions, the following four different reinforcer concentrations were presented: 0% (water), 20%, 40%, and 60%. The concentration was changed at the end of every block of five successive reinforcements. The order of concentrations was random, with the constraint that within a session each concentration occurred three times.

Phase II. Omission of the reinforcer. After Phase I, the baseline conditions were reinstated with the addition that each reinforcer delivery was accompanied by a tone and a light, each lasting 0.5 sec. The reinforcer concentration was 40% throughout this phase. Twenty-five daily sessions were conducted under these conditions, followed by three test sessions.

In the test sessions, the reinforcer was omitted randomly on 50% of the occasions, only the stimuli that accompanied the reinforcer, the tone and light, being presented at each omission. Finally, the baseline conditions of this phase were reinstated for five daily sessions.

RESULTS

Left panel of Figure 1 shows the median duration of all postreinforcement pauses of each animal over the three test sessions as a function of the preceding reinforcer concentration (see Table 1 for the interquartile ranges for each median). The durations of the postreinforcement pauses were very short, ranging between 2.3 sec and 7.3 sec. Even with such short values, however, the durations of the postreinforcement pauses increased as a function of the preceding reinforcer concentration. There was, in terms of the group average, a 77% increase in the duration of the postreinforcement pause between 0% and 60% concentrations. Unconnected points show data from the baseline condition. In the case of postreinforcement pauses, these almost overlapped the data points from the 40% reinforcer concentration used in the test sessions. The running response rate, calculated after excluding postreinforcement pauses, was also an increasing function of the preceding reinforcer concentration (center panel of Figure 1). Since the postreinforcement pauses were short, they contributed little to the measure of overall response rate, and thus the functions relating overall rate and reinforcer concentration (right panel of Figure 1) were similar to the running-rate functions. The response-rate data indicate an interesting contextual effect in relation to the determination of response rate by reinforcer magnitude. For all subjects, both overall and running rates were lower on the 40% concentration when this occurred in the test sessions, where it was intermixed with other concentrations, than on the baseline condition (unconnected points) when the 40% concentration was the only one presented.

Figure 2 shows the local response rates, that is, the response rates calculated separately in successive 11-sec periods of the interreinforcement intervals. The data are from the last

Table 1

Experiment I: number of sessions on the baseline schedule and interquartile ranges of postreinforcement pause durations in the last three baseline and three test sessions.

Animal	*Number of Baseline Sessions*	*Concentration %*	*Postreinforcement Pause in Seconds*	
			Baseline	*Test*
		0		2.5-4.4
		20		3.7-4.9
14	66	40	3.5-4.8	4.0-5.2
		60		5.2-7.3
		0		0.9-3.9
		20		3.3-4.5
15	68	40	4.0-4.8	3.5-4.7
		60		4.3-5.9
		0		2.3-4.2
		20		3.4-4.7
16	65	40	3.5-4.7	3.4-4.8
		60		4.2-5.8

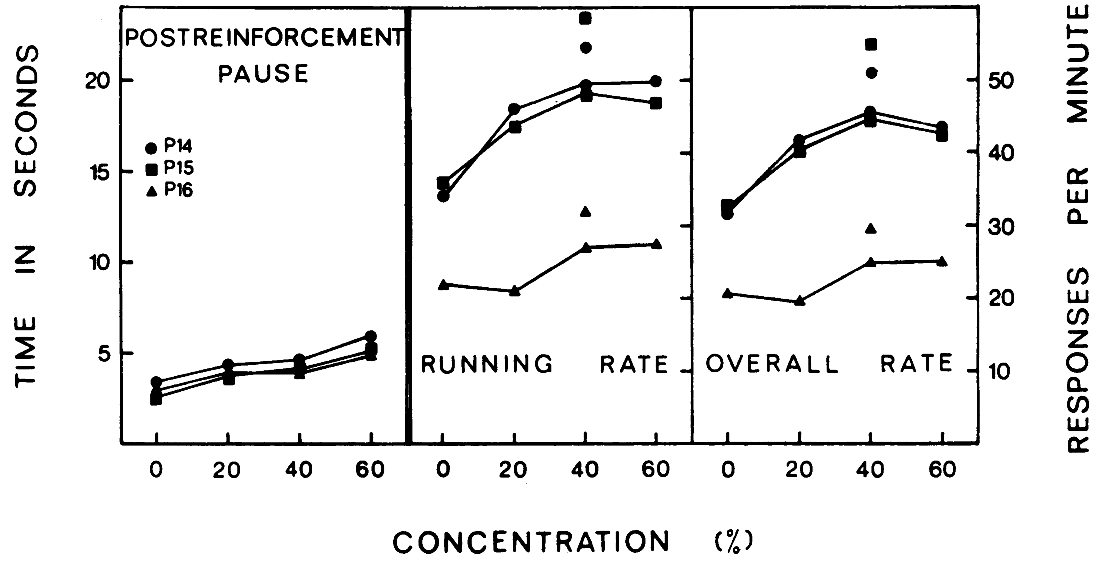

Fig. 1. Experiment I: median durations of postreinforcement pauses (left panel), running response rates (middle panel), and overall response rates (right panel) as functions of reinforcer concentration. Data are from the test sessions. The unconnected points are averages over the last five baseline sessions.

three baseline sessions and from the three test sessions. For the test sessions, the response rates following different concentrations are shown separately. In general, there was no systematic relationship between time elapsing since reinforcement and response rate, the rates remaining approximately the same throughout an interreinforcement interval.

Figure 3 shows the median duration of the pauses (upper panels) and the running rates (middle panels) following reinforcement and following the omission stimulus for the three subjects. The data are from the last five baseline sessions, the three reinforcement omission sessions, and the first five return-to-baseline sessions. In all cases, the pause following omission was shorter than the postreinforcement pause. The durations of the postreinforcement pauses were approximately the same in the baseline, omission, and return-to-baseline sessions, the one exception being the postreinforcement pauses of P16, which showed some increase in the omission sessions. Running rates (middle panel of Figure 3) were generally lower following the omission stimulus than following reinforcement. In general, response rates showed decreasing in the three successive test sessions.

The lower panel of Figure 3 shows local response rates in successive 11-sec segments of the interreinforcement intervals. These data are from the three subjects in the last five baseline sessions, and the three omission sessions. In each condition, response rate remained relatively constant in different parts of the interreinforcement interval. In the early part of an interval, the local response rates following omission of reinforcement were somewhat lower than the response rates following reinforcement, this effect being least marked in the case of Subject P15.

DISCUSSION

The results of this experiment have shown that under the constant-probability VI schedule, where reinforcement does not have an effective temporal discriminative function, the duration of the postreinforcement pause is an increasing function of the concentration of the reinforcer. The orderliness of this relationship was remarkable in view of the fact that absolute durations of the postreinforcement pauses were short. The pauses following the omission stimuli were consistently shorter than the postreinforcement pauses, further suggesting that reinforcement had an unconditioned suppressive effect on lever pressing.

Catania and Reynolds (1968) found that under a number of different VI schedules, response rate was an increasing function of the time elapsed since reinforcement, matching the change in the probability of reinforcement through an interreinforcement interval. Under a constant-probability VI schedule, however, the response rate was approximately constant; this was also the case in the present study. It appears that under a VI schedule, local changes in the response rate reflect changes in reinforcement probability. Thus, if reinforcement probability changes through an interreinforcement interval, the reinforcer acquires discriminative properties signalling any such changes.

Under an arithmetic VI schedule, for example, the probability of reinforcement increases with time since reinforcement. Thus, using an arithmetic VI schedule with the same mean value as the constant-probability VI schedule of the present experiment, the reinforcer would be expected to function as a discriminative stimulus, signalling a low probability of reinforcement soon after reinforcement. Consequently, postreinforcement pauses should be generally higher than in the constant VI schedule, and thus reinforcement magnitude and omission effects should be greater. This was tested in Experiment II.

EXPERIMENT II: ARITHMETIC VI SCHEDULE

Method

Subjects

Three naive male hooded rats, 90 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 and Procedure

The apparatus was the same as in Experiment I, except that the arithmetic VI schedule was programmed using a device that advanced a loop of punched tape a constant distance with each operation. The intervals between reinforcements were determined by the spacing of the holes punched in the tape, the tape being stepped by an electronic timer. Thus, the absolute duration of the intervals depended on the rate at which the timer operated the tape, but the relative duration was independent of the timer. The punched holes in the tape provided a random series of 15 intervals from an arithmetic progression in the following order: 14, 8, 11, 6, 5, 9, 2, 13, 7, 1, 12, 4, 10, 0, 3 (Catania and Reynolds, 1968). The numbers indicate the duration of the intervals between successive reinforcements in multiples of *t* sec, *t* being the setting of the electronic timer. In the present experiment, *t* was 8.5 sec, giving an average interreinforcement interval of 60 sec. The procedure was the same as in Experiment I, and testing commenced only when responding had stabilized under the variable-interval schedule (see Table 2).

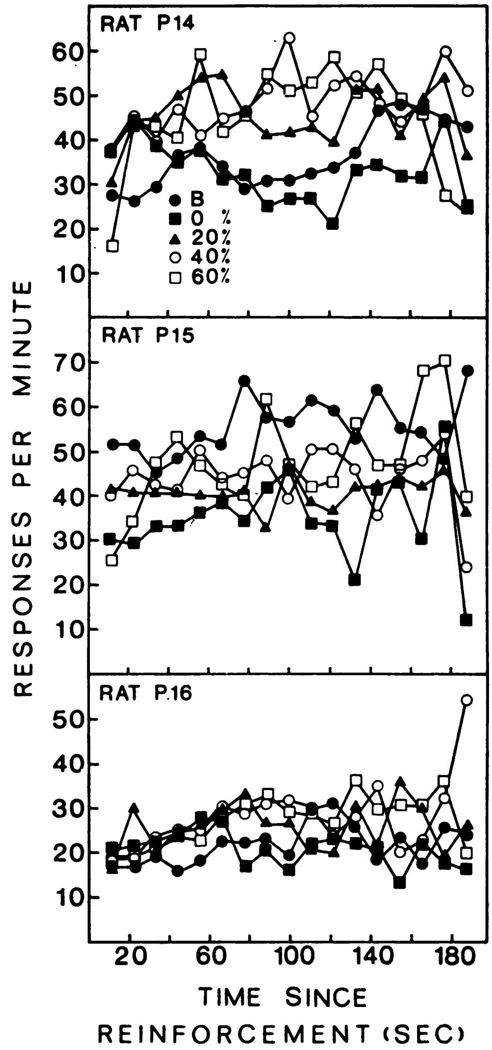

Fig. 2. Experiment I: average local response rates in successive 11-sec segments of interreinforcement intervals. The rates are shown separately for the last five baseline sessions (B) and with respect to the concentration of the preceding reinforcer.

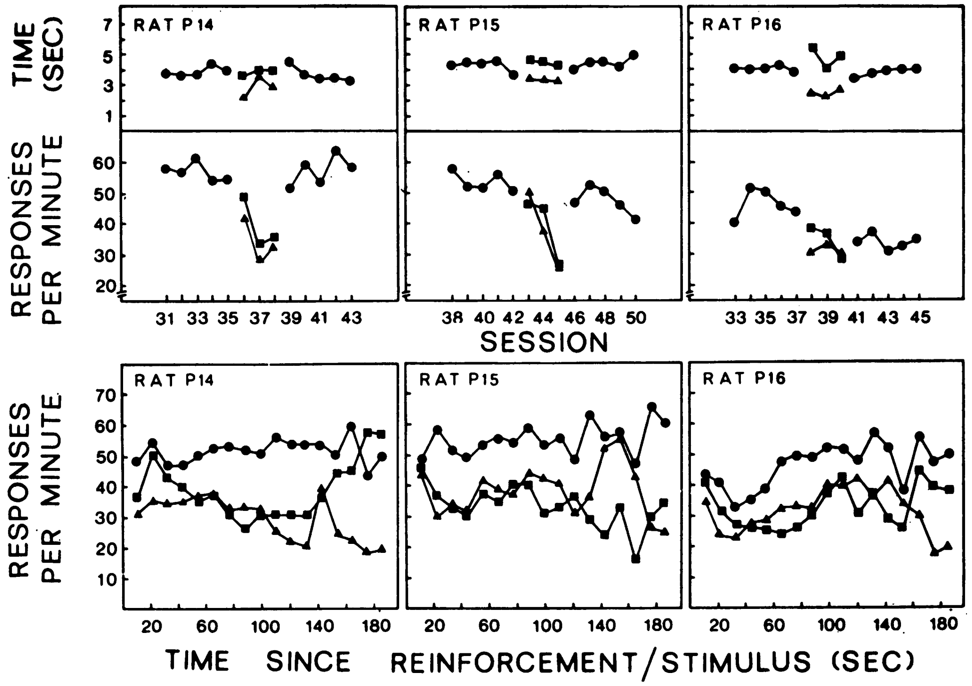

Fig. 3. Experiment I: median durations of postreinforcement pauses (upper panels) and running response rates (middle panels) in the last five baseline sessions, three reinforcement omission sessions, and next five return-to-baseline sessions, in that order. The postreinforcement data during baseline are shown by filled circles and during test sessions by filled squares; the poststimulus data are shown by filled triangles. The lower panels show the local response rates, in 11-sec bins, in the last three baseline sessions preceding the test sessions (filled circles) and in the test sessions following reinforcement (filled squares) and following omission stimuli (filled triangles).

RESULTS

Figure 4 (left panel) shows that for all subjects, the duration of the postreinforcement pause was an increasing function of the reinforcer concentration. (See Table 2 for the interquartile ranges of these data). Taking the group data, there was a 161% increase in the duration of the postreinforcement pause between 0% and 60% concentrations. The relationships between reinforcer concentration and running response rate and overall rate are shown in the center and right panels of Figure 4. As a function of reinforcer concentration, the rates increased for one animal, slightly decreased for one animal, and increased and then decreased for the third animal. The overall and running-rate data, like those of Experiment I, show a contextual effect on the magnitude–response-rate relationship; response rate on the 40% concentration during test sessions (unconnected points) was lower than on the 40% concentration in the baseline condition, the only exception to this being the overall rate data for P22.

Table 2

Experiment II: number of sessions on the baseline schedule and interquartile ranges of the postreinforcement pause durations in the last three baseline and three test sessions.

			Postreinforcement Pause in Seconds	
Animal	*Number of Baseline Sessions*	*Concentration %*	*Baseline*	*Test*
		0		4.0-10.5
		20		8.8-14.1
12	74	40	5.1-16.3	10.9-16.1
		60		13.5-25.7
		0		1.9- 6.8
		20		5.7- 8.3
13	66	40	5.9-16.9	6.7-11.0
		60		13.1-22.3
		0		2.8-18.4
		20		8.3-13.5
22	88	40	11.0-18.6	11.1-14.0
		60		15.2-20.6

Figure 5 shows the local response rates, that is, the rates in successive 8.5-sec periods of an interreinforcement interval (8.5 sec being

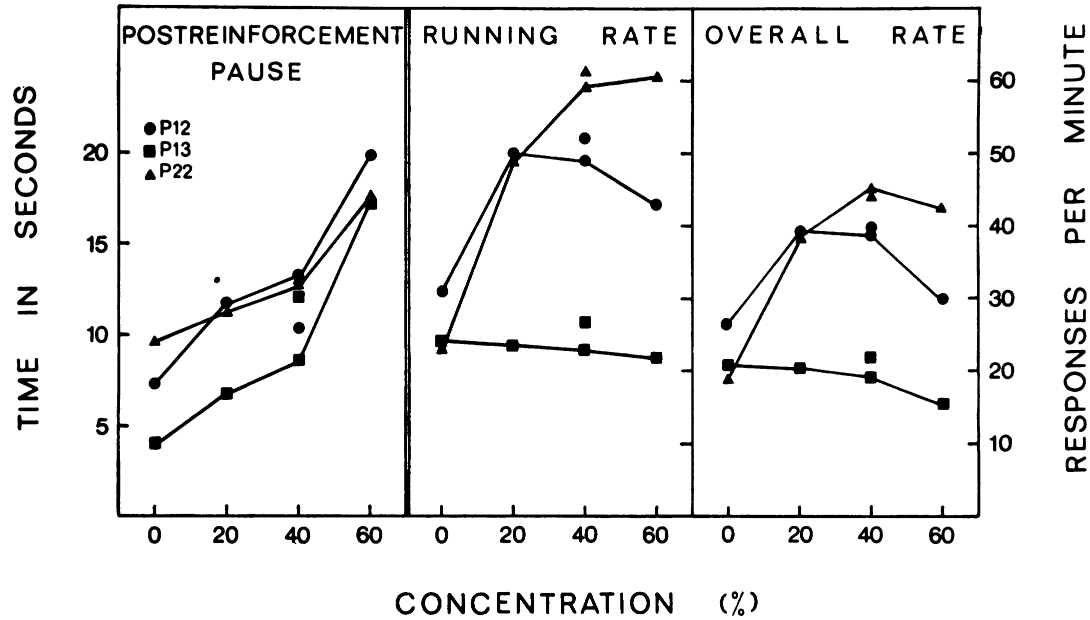

Fig. 4. Experiment II: median durations of postreinforcement pauses (left panel), running response rates (middle panel), and overall response rates (right panel) as functions of reinforcer concentration. Data are from the test sessions. The unconnected points are averages over the last five baseline sessions.

also the *t* value). The data are from the last three baseline sessions and the three test sessions. The response rates following each reinforcer magnitude are shown separately. In every case, the response rate was an increasing function of time since reinforcement, the increase being more marked for P12 and P22 than for P13.

Figure 6 shows for each subject the mean durations of the pauses (upper panels) and the running response rates (middle panels) that followed reinforcement and omission of reinforcement. The data are from the last five baseline sessions, the three reinforcement omission sessions, and the next five sessions when the baseline conditions were reinstated. In all

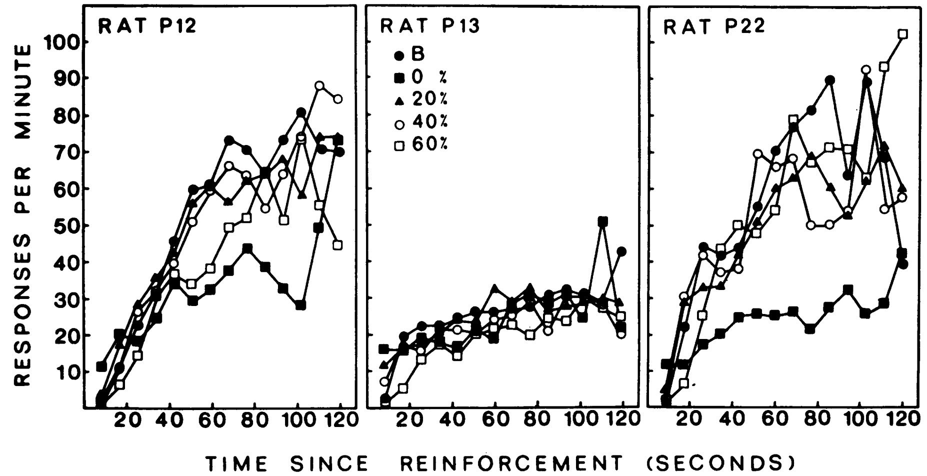

Fig. 5. Experiment II: local response rates in successive 8.5-sec segments of interreinforcement intervals. The rates are shown separately for the last five baseline sessions (B) and with respect to the concentration of the preceding reinforcer.

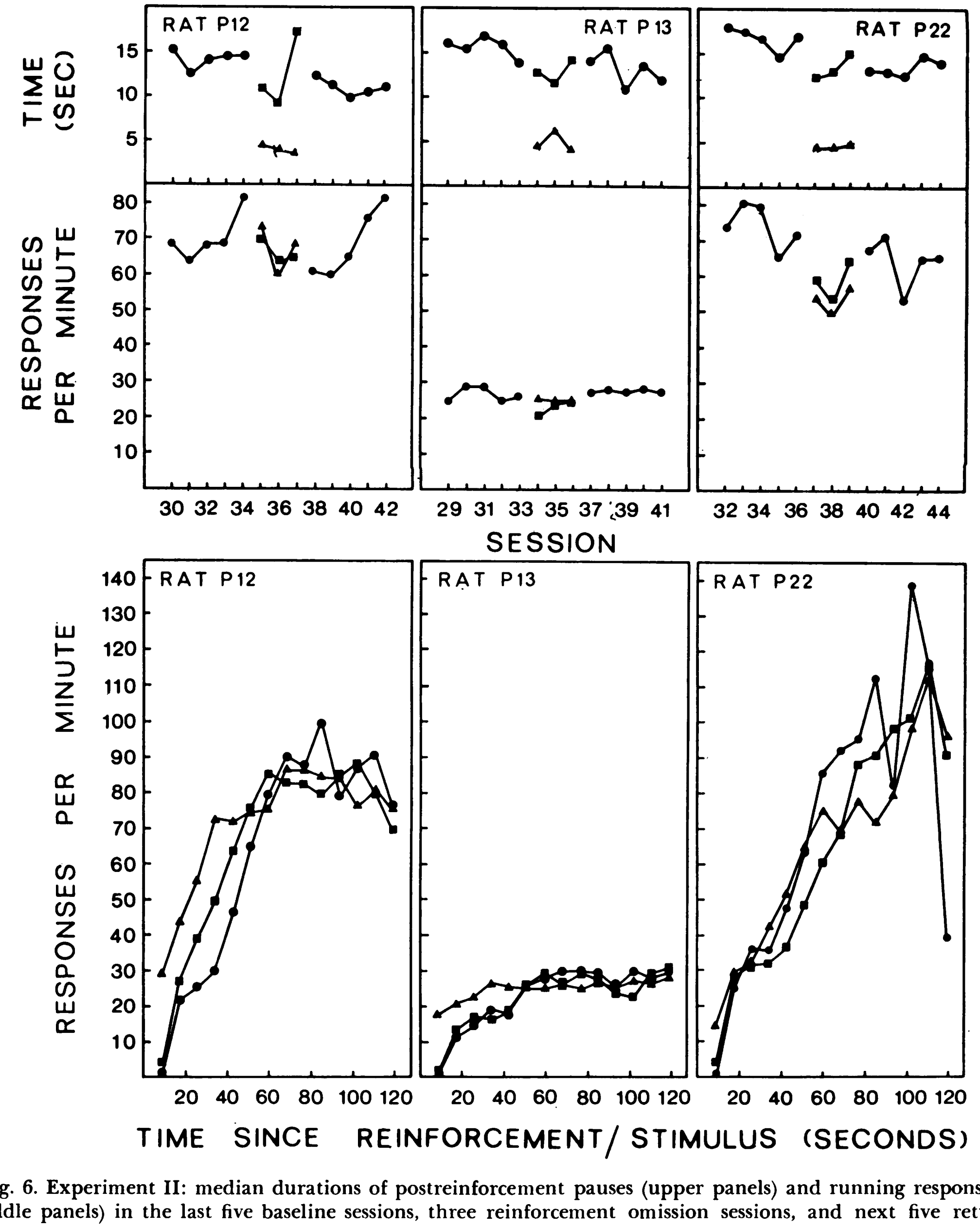

Fig. 6. Experiment II: median durations of postreinforcement pauses (upper panels) and running response rates (middle panels) in the last five baseline sessions, three reinforcement omission sessions, and next five return-to-baseline sessions, in that order. The postreinforcement data are shown by filled circles and during test sessions by filled squares; the poststimulus data are shown by filled triangles. The lower panels show the local response rates, in 8.5-sec bins, in the last three baseline sessions preceding the test sessions (filled circles) and in the test sessions following reinforcement (filled squares), and following omission stimuli (filled triangles).

instances, duration of the pause following the omission stimulus was less than the duration of the postreinforcement pauses. There was no consistent difference, however, between the running rates following reinforcement and following omission of reinforcement.

The lower panel of Figure 6 shows the local response rate in successive 8.5-sec segments of interreinforcement intervals. Response rates were in almost all cases higher in the baseline sessions than in the omission sessions. In baseline and in omission sessions, the local rate was a negatively accelerated function of time since reinforcement, but remained approximately the same in later parts of the longer interreinforcement intervals. For all three animals, the local rate in the early part of an interval was higher when it followed omission than when it followed reinforcement.

GENERAL DISCUSSION

Although the mean interreinforcement-interval value of both schedules used in this study was the same, the behavioral effects engendered by the schedules were very different. Postreinforcement pauses were considerably longer under the arithmetic than under the constant-probability VI schedule. Furthermore, local response rate increased throughout the interreinforcement interval under the arithmetic VI schedule but remained the same under the constant-probability VI schedule (*cf.* Catania and Reynolds, 1968). These results clearly indicate that a reinforcer will function as a discriminative stimulus when its occurrence is predictive of changes in the availability of the subsequent reinforcer. When there was no such change in reinforcement probability, however, as in Experiment I, reinforcement was nevertheless followed by a pause. The duration of this pause varied according to the magnitude of the preceding reinforcer, and also depended on whether the pause was initiated by reinforcement or by stimuli presented in lieu of reinforcement. This evidence suggests that reinforcement has an unconditioned inhibitory or suppressive effect on responding, distinct from any discriminative function it may acquire in the context of the schedule of reinforcement in operation. The results of Experiment II show that such effects are further potentiated by the conditioned inhibitory properties of reinforcement on the arithmetic VI schedule.

In recent discussions, the term inhibition has been used to describe discriminative control by a stimulus signalling the nonavailability of reinforcement (*e.g.*, Hearst, 1972; Staddon, 1972). The present evidence suggests that it would be helpful to distinguish between such conditioned inhibitory effects of the reinforcing stimulus and the kind of unconditioned suppressive effects observed in the present experiments. This would then open the way to a consideration of the ways in which these two functions interact in those situations where they both operate.

In the present study, overall response rate was an increasing function of the preceding reinforcer magnitude under the constant-probability VI schedule and also, to some extent, under the arithmetic VI schedule. Previous studies have reported, however, a positive relationship between reinforcer magnitude and response rate on arithmetic VI schedules (*e.g.*, Conrad and Sidman, 1956; Davenport, Goodrich, and Hagquist, 1966; Guttman, 1953). The difference between previous reports and the present results may perhaps be due to the fact that magnitude changes were made within sessions in the present experiment but not in previous studies. The type of magnitude effect reported here is known to be dependent on the context of presentation where different magnitudes are contrasted closely in time (Harzem, Lowe, and Davey, 1975).

Comparing local response rates under the two VI schedules used here, it is interesting to note that in the early part of an interval, the local rate was higher following reinforcement than following reinforcement omission under the constant-probability VI schedule, whereas the better-known effect, where response rate is higher after omission (Amsel and Roussel, 1952; Staddon and Innis, 1969; Zeiler, 1972), was observed only under the arithmetic VI schedule. It appears therefore that elevation of response rate following reinforcement omission is observed when the reinforcing stimulus signals a period of nonreinforcement (see also McMillan, 1971; Staddon, 1972), but not when the reinforcer has no such predictive significance.

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