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Sequential effects of response-opportunity duration

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Rats were conditioned to respond on a schedule in which reinforcements became available every 2 min. After each reinforcement, the lever was retracted for either 40 or 80 sec and reintroduced so that the subject could respond during the final 80 or 40 sec, respectively. Response rates were the same regardless of the interval during which the subjects could respond, but they made more total responses when they could respond for 80 sec. The subjects also made more responses if they had been able to respond only during the final 40 sec of the preceding interval.

A number of variables have been demonstrated to affect fixed-interval (FI) performance, among which is the duration of the preceding interval. Innis (1978) reported a study in which pigeons earned several successive reinforcements on an FI 1-min schedule when one color was displayed on the key, and earned several successive reinforcements on an FI 3-min schedule when another color was displayed. Overall response rate was higher, and post-reinforcement pauses were shorter, during the first 1-min interval than during later 1-min intervals in the same block.

Meltzer (1987) used a procedure in which rats were reinforced on an FI 1-min schedule when light was on, and on an FI 5-min schedule when light and tone were on. However, in that study, the interval sequence was such that intervals of either duration were equally likely to be followed by intervals of the same or of the other duration. Rates were higher during 1-min intervals, although the absolute number of responses was greater during 5-min intervals. Rates were also higher during current intervals of both 1- and 5-min duration if the preceding interval had been 5-min.

The question raised by such results concerns the parameters during preceding intervals that may affect the response rate during current intervals. For example, the rats may have responded at higher rates following a 5-min interval because the time between preceding reinforcements was longer than in a 1-min interval. On the other hand, the variable producing higher rates may have been the greater number of responses, or the lower response rate, during the preceding 5-min interval. In the present experiment, the time between reinforcements was held constant but the time during which the subjects could respond differed.

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METHOD

Subjects

The subjects were 5 male Long-Evans rats that were approximately 120 days old at the beginning of the experiment. Each subject's weight was recorded for 5 days before food deprivation began and the mean weight over these 5 days served as the subject's free-feeding weight. Each subject was maintained at 85% of its free-feeding weight during the course of the experiment. Water was available in each subject's home cage but not in the experimental chamber.

Apparatus

Three identical experimental chambers with interior dimensions of 21.0 × 30.5 × 18.0 cm were used. A BRS/LVE retractable rodent lever was mounted 3.5 cm above the floor and centered 4 cm from the left wall. The lever required a minimum force of approximately 0.2 N for operation. Lever insertion and retraction each took approximately 2 sec. A pellet dispenser delivered 45-mg food pellets to a hopper mounted at the midline of the front wall, just above the floor. Two incandescent white lights, each emitting approximately 127 cd/m² measured 0.5 cm from the source, were located on the front wall. One light was centered 4.2 cm above the lever (i.e., 7.7 cm above the floor and 4.0 cm from the left wall). The other light was at the same height and 4.0 cm from the right wall. Both lights remained on throughout an experimental session. An Apple IIe computer and solid state interface equipment were located in an adjacent room to provide experimental control and recording.

Procedure

An autoshaping technique was used to establish barpressing. The subjects were placed in the experimental chamber with both levers retracted. After a variable time with a mean of 20 sec, a lever was inserted. A food pellet was delivered after 8 sec if the subject did not press the lever, but was delivered immediately if the subject did press the lever. The lever then was retracted and the cycle was repeated.

Following this stage of shaping, a new procedure was introduced. The subjects were placed on an FI schedule in which the first response occurring 1 min after the last food-pellet reinforcement produced another food-pellet reinforcement. There were 17 intervals in each session. However, the lever was withdrawn for the first 20 sec after reinforcement in some intervals and for the first 40 sec after reinforcement in others. For example, the first interval would last for 40 sec, after which a response was reinforced. The lever might then be retracted for 40 sec, after which it would be reinserted. After an additional 20 sec had elapsed, the first response was reinforced. The lever could then be retracted for either 20 or 40 sec and then reinserted. The first response after an additional 40 or 20 sec, respectively, was reinforced. Intervals in which the lever was available to the subject for 40 sec after having been retracted for 20 sec were call long intervals. Those in which the lever was un-

available to the subject during the first 40 sec were called short intervals. The sequence of intervals was arranged so that a long interval was equally likely to be followed by either a long interval or a short interval. Similarly, a short interval was equally likely to be followed by either a long interval or a short interval.

After three sessions, the procedure was altered so that the minimum time between reinforced responses was 2 min. The lever was unavailable to the subject for the first 40 sec of a long interval and was retracted during the first 80 sec of a short interval. The procedure still ensured that long intervals were equally likely to be followed by long and short intervals, and that short intervals were equally likely to be followed by long and short intervals. Four different interval sequences were used during the 32 sessions in this phase of the experiment. Each sequence was used once in a block of four experimental sessions, and the order in which sequences were used in a block of sessions was varied. No other changes were made.

Responses were recorded in successive 10-sec bins during the portion of long and short intervals when the lever was available to the subjects. Data from long intervals preceded by long intervals were recorded separately from data from long intervals preceded by short intervals. Similarly, data from short intervals preceded by short intervals were recorded separately from data from short intervals preceded by long intervals. Sessions were scheduled 5 days a week.

RESULTS

Data from the last eight sessions were analyzed. Response rates might have been expected to be higher during short intervals, but 4 of the 5 subjects responded at higher rates during long intervals. An analysis of variance showed that neither the current nor the preceding interval duration had a significant effect on response rates. Table 1 shows mean response rates throughout each type of interval.

In additional analyses, we examined the subjects' response rates during the first and last 40 sec of lever availability in long intervals relative to their rates during the 40 sec of lever availability in short intervals. Table 2 shows mean responses rates during the 40 sec of short intervals (i.e., 80-120 sec after the preceding reinforcement) when the lever was available to the subject. It also

Table 1
The Mean Response Rate (responses/second) During Long (80-sec) and Short (40-sec) Intervals After Long and Short Preceding Intervals

Preceding Interval	Current Interval		
	Long	Short	*M*
Long	1.21	0.98	1.10
Short	1.33	1.15	1.24
M	1.27	1.07	

Table 2
Mean Response Rates (responses/second) During the First and Last 40 sec of Long Intervals and During the 40 sec of Short Intervals

Preceding Interval	Current Interval		
	Long		
	First 40 sec	Last 40 sec	Short
Long	0.75	1.68	0.98
Short	0.86	1.80	1.15

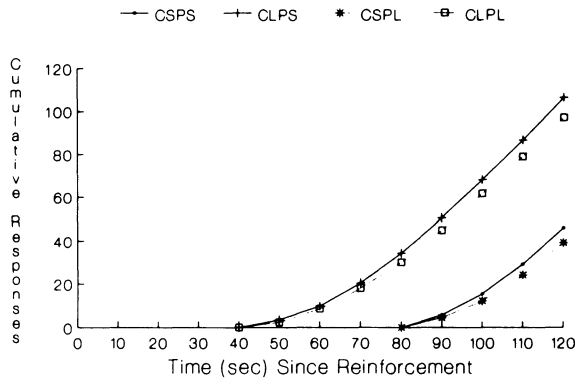

Figure 1. Mean cumulative responses over the 2-min interreinforcement interval. The data are separated into current short, preceding long (CSPL), current short, preceding short (CSPS), current long, preceding long (CLPL), and current long, preceding short (CLPS) intervals. Responses were recorded during successive 10-sec bins. During long intervals, the lever was available for the last 80 sec of the interreinforcement interval. During short intervals, the lever was available for the last 40 sec.

shows mean response rates during the first 40 sec of lever availability in long intervals (i.e., 40-80 sec after the preceding reinforcement) as well as mean responses rates during the last 40 sec of long intervals (i.e., 80-120 sec after the preceding reinforcement).

Although the subjects responded at lower rates during the first 40 sec of long intervals than during the 40 sec of short intervals, the difference was not significant. Table 2 shows that rates during the first 40 sec of long intervals, as well as during the short intervals, were higher if the preceding interval had been short. However, the differences were not significant and these data suggest that the subjects responded the same way to the insertion of the lever regardless of how much time had passed since the last reinforcement.

All 5 subjects responded at higher mean rates during the last 40 sec of long intervals than during short intervals. An analysis of variance showed that this difference was significant [$F(1,4) = 13.03$, $p < .03$]. All 5 subjects also responded at higher rates during the last 40 sec of the long interval if the preceding interval had been short. Four of the 5 subjects also responded at higher rates during short intervals if the preceding interval had been short, and the effect of preceding duration was significant [$F(1,4) = 8.71$, $p < .05$].

It was possible that rate measures would not reveal differences within the 40-sec blocks being examined, so the cumulative responses during successive 10-sec bins throughout each interval were also analyzed. Figure 1 shows the mean cumulative responses over the 2 min between reinforcements. The data are separated into four types of intervals: long intervals preceded by long intervals, long intervals preceded by short intervals, short intervals preceded by long intervals, and short intervals preceded by short intervals. Obviously, there were no responses before the lever was available to the subject,

so responses began after 40 sec in long intervals and after 80 sec in short intervals. As with the rate measure, one analysis compared cumulative responses over the first 40 sec following lever insertion—that is, 40-80 sec after the preceding reinforcement in long intervals and 80-120 sec after the preceding reinforcement in short intervals. Another analysis compared cumulative responses during both long and short intervals 80-120 sec after the preceding reinforcement.

Analysis of cumulative responses during the first 40 sec of long and short intervals showed a significant increase over successive bins [$F(3,12) = 36.73$, $p < .001$], but the increase was more rapid during short intervals, and this interaction was significant [$F(3,12) = 7.70$, $p < .01$]. Tests of simple main effects showed that cumulative responses were significantly higher during short intervals after 30 and 40 sec but not after 10 and 20 sec.

In contrast to response-rate comparisons, the more rapid increase in cumulative responses during short intervals indicated that the subjects did discriminate their temporal position within the interreinforcement interval.

The data examined in the analysis of cumulative responses during the last 40 sec of long and short intervals may best be understood by the following example. Suppose a subject made a total of 200 responses during the first 40 sec of a long interval. If the subject then made 230 responses by 50 sec, 270 responses by 60 sec, 305 responses by 70 sec, and 340 responses by 80 sec, the cumulative responses over the last four 20-sec bins were 30, 70, 105, and 140 responses, respectively. These were the long-interval cumulative responses that were compared with the short-interval cumulative responses at comparable times. The subjects made significantly more responses during the 40 sec of long intervals [$F(1,4) = 12.73$, $p < .05$] and also made significantly more responses when the preceding interval was short [$F(1,4) = 10.17$, $p < .05$]. Although cumulative responses increased significantly over bins [$F(3,12) = 13.68$, $p < .001$], the increase was greater during long intervals than during short intervals [$F(3,12) = 13.68$, $p < .001$]. Tests of simple main effects showed that the difference between long- and short-interval cumulative responses was significant during the last three 10-sec bins. Cumulative response during both long and short intervals increased more rapidly over bins if the preceding interval had been short [$F(3,12) = 7.49$, $p < .01$], and tests of simple main effects showed that the effects of preceding interval duration were significant during the last three bins.

DISCUSSION

Did the rats respond at higher rates following long periods of responding than following short periods, as had been the case when long and short FIs were used? The answer is negative when the entire interval, or only the first 40 sec following lever insertion, is considered. However, the effects of response time during the preceding interval are apparent when the 40 sec just before the next reinforcement are considered. During that time, a short response period in the preceding interval led to increased response rates during the current interval. This effect is exactly opposite to that found when rats were allowed to respond throughout long and short intervals and the interval duration was the actual time between reinforcements (Meltzer, 1987). Moreover, cumulative responses increased more rapidly during both long and short intervals if the response period preceding the interval had been short.

One possible explanation for these differences would be that a temporary fatigue or inhibitory state followed long response intervals. The problem is that temporary inhibitory effects should have diminished as the interval proceeded rather than becoming stronger. In addition, such a hypothesis would imply that subjects should consistently respond at higher rates and increase their responding more rapidly following short intervals, and the opposite findings by Innis (1978) and Meltzer (1987) are what prompted this study. Nor could the results be due to a larger number of responses in long intervals. Meltzer (1987) found that subjects made significantly more responses during 5-min than during 1-min FIs, but they still responded at higher rates following 1-min FIs.

The current results seem consistent with the hypothesis that long interreinforcement times and long periods of response opportunity have opposite effects. The former serves to increase rates during a following interval; the latter series serves to decrease rates. In standard FI procedures, interreinforcement time and response periods are the same and necessarily covary. However, as a subject learns to discriminate different FI durations, it confines its responses to terminal segments of the interval. Thus, if a subject responded during the last third of the interval, the difference between FI 1- and FI 3-min would lead to a 2-min difference in interreinforcement time but only a 40-sec difference in the period during which a subject responded. The relatively greater change in interreinforcement time would be expected to have a stronger sequential effect on performance. Since interreinforcement time was held constant in this experiment, the effect of the different response-opportunity periods caused the subjects to make more responses if the preceding interval had been short.

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