SEQUENTIAL EFFECTS OF INTERVAL DURATION ON FIXED-INTERVAL PERFORMANCE

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The bar pressing of rats was reinforced on a multiple fixed-interval schedule. The schedule intervals were 1 and 5 min long, and the 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 and after 5-min intervals. Best fit equations for cumulative responses during the 5-min intervals produced very similar exponents regardless of preceding duration. It was concluded that preceding duration may have affected the subjects' performances through direct effects on temporal discrimination.

Key words: fixed interval, sequential effects, interval duration, temporal discrimination, lever press, rats

A number of studies have shown that the rate at which animals respond on a fixed-interval (FI) schedule can be affected by variables other than the length of the current interval. Much of this work has examined the effect of reducing or omitting a scheduled reinforcement. The results of these studies have been quite consistent. Either the omission (Jensen & Fallon, 1973; Kello, 1972; Scull, Davies, & Amsel, 1970; Staddon & Innis, 1969; Zeiler, 1972) or reduction (Meltzer & Howerton, 1973, 1975, 1976; Staddon, 1970) of a scheduled reinforcement led to increased rates of response during the subsequent interval.

More recently there also has been evidence suggesting that duration of the preceding interval can have effects similar to those produced by variation in reinforcement magnitude. Meltzer and Howerton (1976) reinforced rats' responding using two different alternating pairs of FI schedules on alternate days. On odd days, the alternate intervals were 1 min and 3 min long. The 1-min intervals ended with either a one- or three-pellet reinforcement, whereas the 3-min intervals always ended with a two-pellet reinforcement. On even days, the alternate intervals were 5 min and 3 min long. The 5-min intervals ended with either one or three pellets, whereas again, the 3-min interval ended with two pellets. A different compound stimulus was present dur-

ing each of the three FI schedules, but there was no discriminative stimulus correlated with the number of pellets to be delivered at the end of the FI 1-min or FI 5-min schedules. The rats responded at higher rates during intervals that followed a one-pellet reinforcement than during those that followed a three-pellet reinforcement. They also responded at higher rates during FI 3-min on days when the alternate was FI 5-min, as compared to their rates during FI 3-min on days when the alternate was FI 1-min. There was no interaction between rate differences following different reinforcement magnitudes and those following different interval durations. Apparently the two variables had similar effects on subsequent response rates but were independent of each other.

Innis (1978) also studied the effects of interval durations that varied within sessions. Key pecking of 4 pigeons initially was reinforced on an FI 1-min schedule. Key pecking of 2 other pigeons was reinforced on an FI 3-min schedule. Sessions were divided into several 12-min blocks during which the light behind the key was red or green in alternate blocks. After performance had stabilized, reinforcers were available on an FI 1-min schedule during one set of 12-min blocks and on an FI 3-min schedule during the alternate set of 12-min blocks. Innis found that post-reinforcement pauses were shorter during the first FI 1-min than during later 1-min FIs in the same block. Pauses also were longer during the first FI 3-min interval in a block than during later intervals in the block. Similar ef-

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fects were found when overall response rates were compared. However, only 4 of the 6 subjects responded at higher overall rates during the 1-min intervals. It is difficult to interpret the results of this study because of the sequential dependencies that may have affected the results. The differences between the first FI and later FIs in a block may have resulted because the first FI was always preceded by an FI of different duration, because it was always followed by other FIs of the same duration, or because of some interaction of preceding and subsequent intervals.

These studies all showed that rate during an interval could be affected by conditions during the preceding interval. However, none has shown that such effects occur as a function of preceding interval durations when the following interval duration was unpredictable. Nor have data been presented on response distributions within the interval, which would show how long the effects of the preceding interval last and when they are at a maximum.

METHOD

Subjects

The subjects were 8 male hooded rats bred in the university vivarium. They were approximately 120 days old at the beginning of the experiment. Each subject was maintained on a food-deprivation schedule that consisted of the food received as reinforcement plus free access to food for 1 hr after each experimental session. Water was available in each animal's home cage but not in the experimental chamber. Experimental sessions were conducted 5 days a week.

Apparatus

Two identical experimental chambers with interior dimensions of 21.0 by 30.5 by 18.0 cm were used. A BRS/LVE rodent lever (Model 121-05), which required a minimum force of approximately 0.2 N for operation, was located on the left side of the front wall, 3.5 cm above the floor. A pellet dispenser delivered 45-mg Noyes 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 either side of the front wall 9.0 cm above the floor. Speakers mounted on the housing of each

chamber, behind the front wall, provided 830-Hz tones, 2.5 dB above background noise. White noise was present continuously in the experimental room to mask extraneous sounds. Electromechanical programming and recording equipment was located in an adjacent room.

Procedure

During the first session, each lever press could produce food, and when necessary, lever pressing was shaped by successive approximations. Lever presses were then reinforced on a fixed-interval schedule during the rest of the experiment. During the second, third, and fourth sessions, there were 17 intervals in each session. When the lights were on, FI 30-s was in effect. When the lights and tone were both on, FI 150-s was in effect. Light and tone were both turned off as soon as the last reinforcement of the session had been delivered. The reinforcement at the end of each interval consisted of two 45-mg Noyes pellets, delivered 0.5 s apart. The 17 intervals were arranged so that 8 of the last 16 intervals were 30 s long and the other eight were 150 s long. The first interval could be of either duration and was changed from session to session, as was the order of the remaining intervals. Eight different sequences of intervals were used during the experiment. A further restriction was that there was an equal probability that the 30-s intervals would be followed by 30-s and 150-s intervals. That is, of the eight 30-s intervals, four were followed by another 30-s interval and the other four were followed by 150-s intervals. Because the last interval of the session could not be followed by another interval, the first and last intervals of the session were always of the same duration. In exactly the same way, the eight 150-s intervals were followed by 30-s intervals on four occasions and 150-s intervals on the other four occasions. Of course it follows that the last eight 30-s intervals were preceded by four 30-s intervals and four 150-s intervals, as were the last eight 150-s intervals.

The interval durations were changed to 1 min and 5 min during the sixth session, but the procedure was otherwise unaltered until the subjects completed 37 sessions. The last 32 sessions consisted of four 8-session blocks. Each of the eight sequences of FIs was used once during each 8-session block. Data from the last 8 sessions, which were the fourth rep-

Table 1

Mean response rates and standard deviations (*SD*) during 1- and 5-min intervals after preceding intervals of different durations.

Subject	Preceding interval duration							
	1 minute				5 minutes			
	Current interval				Current interval			
	1 minute		5 minutes		1 minute		5 minutes	
	Mean	<i>SD</i>	Mean	<i>SD</i>	Mean	<i>SD</i>	Mean	<i>SD</i>
11	13.8	4.9	4.2	1.0	17.0	3.6	8.5	3.0
12	41.4	10.4	31.3	9.3	48.2	12.5	41.6	10.3
13	14.9	2.1	7.8	1.7	16.6	3.7	9.6	1.7
14	25.6	12.1	24.4	5.7	29.5	11.3	28.2	6.5
15	17.9	7.1	9.8	1.4	20.4	5.4	13.3	4.0
16	47.2	10.4	38.3	5.8	53.3	9.1	43.4	11.1
17	18.6	5.3	10.2	5.8	16.8	2.8	14.6	2.8
18	23.0	6.2	26.9	10.5	22.0	5.4	32.4	8.3

etition of each sequence, were analyzed. All responses were recorded during the 1-min interval and responses during the 5-min interval were recorded during five successive 1-min bins. In addition, responses were recorded separately for 1-min intervals that had been preceded by 1-min intervals and for 1-min intervals that had been preceded by 5-min intervals. Responses were recorded separately during 5-min intervals that had been preceded by 5-min intervals and for 5-min intervals that had been preceded by 1-min intervals.

RESULTS

Table 1 shows that 7 of the 8 subjects responded at higher rates during the FI 1-min than during the FI 5-min components; the sole exception was Subject S18. The higher rates during FI 1-min occurred in at least six of the eight sessions for 6 of the subjects, but in only four of eight sessions for Subject S14. Subject S18 also was consistent in that it responded at higher rates during FI 5-min for seven sessions.

Regarding the question as to whether the duration of the preceding interval would affect response rate during the current interval: Table 1 shows that all subjects except S17 and S18 responded at higher rates during FI 1-min intervals preceded by FI 5-min than during those preceded by FI 1-min intervals. This happened in at least six of the eight sessions for 5 subjects and in five sessions for S14. Subjects S17 and S18 did not show this effect.

They responded more quickly following FI 1-min, but their rate differences were less than two responses/minute and they responded at higher rates following FI 5-min in three sessions. Table 1 also shows that each subject responded at higher rates during FI 5-min intervals following FI 5-min than during those following FI 1-min intervals. This was true in at least six of eight sessions for every subject.

An analysis of variance showed that the mean response rate of 26.6 responses/minute during FI 1-min was significantly higher than the mean response rate of 21.5 responses/minute during FI 5-min [$F(1, 7) = 5.74, p < .05$]. Mean response rate during an interval that followed FI 5-min was 26.0 responses/minute, and mean response rate during intervals following FI 1-min was 22.2 responses/minute; this difference also was significant [$F(1, 7) = 11.84, p < .01$].

Different preceding-interval durations also affected response distributions within an interval. These data were recorded only during the FI 5-min components because of equipment limitations. Figure 1 shows the mean cumulative responses of the subjects during each successive minute of 5-min intervals preceded by either a 1-min or by another 5-min interval. The data are plotted on log-log coordinates and a line based on the best fit equation for cumulative responses during the last 4 min of each interval is included. Responses during the first minute were not used in calculating the equations because there were sev-

Fig. 1. Mean cumulative responses for each successive minute of the 5-min FI schedule cycles during the last eight sessions of the experiment. The vertical and horizontal axes are scaled logarithmically and data are presented separately for intervals that followed 1-min intervals (filled circles) and for those that followed 5-min intervals (open circles). The best fit curves are shown for each subject's cumulative responses along with the best fit equation. The number in parentheses following each equation is the proportion of variance accounted for by that equation.

eral intervals during which subjects made no responses during the first minute of an interval. The value in parentheses that follows each equation is the proportion of variance accounted for by that equation. As can be seen,

no equation accounted for a proportion less than .99. All 8 subjects had higher coefficients in those equations based on data from intervals that followed an FI 5-min component. A two-tailed *t* test confirmed that the difference

between coefficients was significant ($t = 2.55$, $df = 7$, $p < .05$). Inasmuch as these coefficients are a measure of the projected intercepts of the equations, it follows that the intercepts were different after FI 1-min and FI 5-min.

Six of the 8 subjects had higher exponents in those equations based on data from intervals that followed an FI 1-min component, the exceptions being S12 and S15. However, 3 of these 6 subjects' exponents differed by less than 0.1. The exponents are measures of the slopes of the lines in Figure 1, and although the slopes differ among subjects, the slopes for each individual subject are quite similar. A two-tailed t test was performed to compare the exponents in the post-5-min and post-1-min equations. There was no significant difference ($t = 2.16$, $df = 7$, $p > .05$). Therefore, it appears that the best fit equations for the same subject usually differed in their projected intercept rather than in their slope.

The differences in mean number of responses during each individual minute of the 5-min interval also were examined. Several aspects of these data are important. The response rates almost always continued to increase during each successive minute of the 5-min interval regardless of the duration of the preceding interval. Higher mean rates also occurred during each of the last 4 min of FI 5-min that followed FI 5-min than during comparable periods that followed FI 1-min, and this effect was quite consistent. There were 32 comparisons for each subject, four 1-min periods in each of eight sessions, and 7 of the 8 subjects had higher rates following FI 5-min in at least 24 comparisons. Subject S13 showed the same difference in 20 of the 32 comparisons. However, as Figure 2 shows, the rats began to respond at higher rates earlier in the interval if it followed another 5-min interval. An analysis of variance showed that response rate increased significantly over minutes [$F(4, 28) = 20.23$, $p < .01$] and was higher during intervals that followed FI 5-min than during those that followed FI 1-min [$F(1, 7) = 12.05$, $p < .025$]. The ratio of post-5-min responses to post-1-min responses reached a maximum during the second minute of the 5-min interval for 6 subjects. For S12 and S15, the maximum ratio was during the third minute of the interval. If the absolute difference in responses is considered, only one subject, S14, reached a maximum during the second

minute. Four subjects, S12, S16, S17, and S18, had the maximum difference between their post-5-min and post-1-min responses during the third minute of the interval, whereas the last 3 subjects, S11, S13, and S15, had their maximum difference during the fourth minute of the interval. Thus, although response rates increased throughout the interval, the effect of the duration of the preceding interval was strongest during the middle portion of the current interval. The analysis of variance confirmed the significance of the interaction between minute of the current interval and duration of the preceding interval [$F(4, 28) = 10.14$, $p < .01$]. A test of simple main effects showed that rates following FI 5-min were higher than rates following FI 1-min during each of the last 4 min but not during the first minute.

It should be recognized that the difference between cumulative responses, shown in Figure 1, continued to increase in each successive minute of the 5-min FI. A mathematically perfect fit to a power function matched to cumulative response differences would have required the maximum rate difference to occur during the final minute of the FI 5-min schedule cycle. The cumulative differences not only would have had to increase in each successive minute, but also would have had to increase by progressively greater amounts. However, the equations represented graphically in Figure 1 were based on cumulative responses, not on the cumulative difference between responses. The magnitude of the discrepancy between the observed results and the best fit equations obviously was minimal over the total range of cumulative responses, because the equations were able to account for virtually all of the variance in the results.

DISCUSSION

When rats responded on multiple fixed-interval schedules, the duration of the preceding interval had consistent effects on current performance; longer preceding intervals led to higher rates in the current interval and shorter preceding intervals led to lower rates in the current interval. These effects were not due to differences in the probability that the current interval would be followed by another interval of the same, or different, duration.

Some explanations for the effect of preced-

Fig. 2. Mean responses during each successive minute of 5-min intervals of the last eight sessions. Responses that followed 1-min and 5-min intervals are shown separately.

ing interval duration may account for parts of these results but not for all of them. For example, Staddon (1983) assumed that reinforcement functions as a time marker that predicts nonreinforcement during the early part of the next interval. The omission or reduction of reinforcement was assumed to reduce subsequent inhibitory control and produce a higher response rate during the next interval. A hypothesis such as this could be extended to account for the effects of preceding-interval duration. It might be argued that a reinforcement at the end of a short interval would be superimposed on enduring inhibitory effects of the preceding reinforcement and would have effects comparable to those produced by increased reinforcement magnitude. That is, response rate during the following interval would be reduced. By the same interpretation, reinforcement at the end of a long

interval would occur well after the inhibitory effects of the preceding reinforcement and would have effects comparable to reduced reinforcement magnitude. Response rate during the following interval would be increased. This explanation would have the advantage of accounting for the similarities in the effects of different reinforcement magnitudes and different interval durations. The major weakness of the hypothesis is that Staddon assumed that the inhibitory effects occurred because reinforcement predicted a period of nonreinforcement on FI schedules. Why then should the effects of preceding-interval duration persist during the last minute of FI 5-min components when reinforcement was imminent? And why should response-rate differences in the FI 5-min components be most pronounced during the middle of the interval?

It is tempting to speculate regarding the

subjects' temporal discriminations and the processes that governed response emission. Several plausible hypotheses could be developed to account for the results, but none could be proven on the basis of these data. From this viewpoint, a salient feature of the data is subjects' beginning to respond later in intervals that followed FI 1-min than in intervals that followed FI 5-min. This relationship is revealed by the difference between coefficients in the best fit equations as well as by the fact that the ratio of post-FI 5-min to post-FI 1-min responses was at a maximum during the second or third minute of the current interval. The subjects may have begun to respond later following FI 1-min because of inhibitory effects such as those suggested by Staddon (1983), but the problems an inhibitory hypothesis encounters have already been discussed. Another possibility is that the preceding-interval duration, or reinforcement magnitude, may have direct effects on temporal discrimination. In this study a preceding 1-min interval may have induced the subject to behave as if the current interval duration were greater than its actual value. Just as these subjects responded at lower rates during FI 5-min than during FI 1-min, and just as they responded after longer postreinforcement pauses during FI 5-min than during FI 1-min, so they responded at lower rates and increased their response rates later in an FI 5-min that followed FI 1-min.

The best fit equations also provide some support for this hypothesis. The projected intercepts of the equations were different but the slopes were not. The similarity of slopes is a measure of the distribution of responses within the two types of interval. Because the slopes were similar, it is apparent that the proportion of total responses during each minute of a 5-min interval was approximately the same regardless of the duration of the preceding interval. For example S13 emitted .04, .12, .20, .27, and .37 of its post-FI 1-min responses in Minutes 1 through 5, respectively; it emitted .04, .13, .21, .28, and .34 of its post-FI 5-min responses in Minutes 1 through 5, respectively. If the cumulative responses shown in Figure 1 had been plotted as cumulative proportions of total responses, the data from the post-FI 1-min and post-FI 5-min intervals would have been almost superimposed on each other. Several studies (e.g., Catania & Reyn-

olds, 1968; Dukich & Lee, 1973) have shown that distribution of cumulative responses within an interval was not affected by interval duration, so these results would be consistent with the hypothesis of a shift in temporal discrimination. However, an explanation based on inhibition would seem to require that responses be more heavily concentrated in the later portions of an interval.

The main problem with the hypothesis that preceding-interval duration affects current temporal discrimination is that it does not explain why the differences in the number of responses a subject emits should be greatest during the middle, rather than the late, portions of the interval. Assuming that response rate would increase until reinforcement was due, which was the observed result in this study, the differences between post-FI 1-min and post-FI 5-min responses should have been greatest during the last minute of the interval. Apparently other processes are also affecting performance, but it is not clear what they might be.

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