SPACED RESPONDING IN RATS AS A FUNCTION OF SOME TEMPORAL VARIABLES¹

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Three experiments were performed comparing spaced responding maintained by two different DRL schedules of reinforcement. In the first two experiments, the two schedules differentially controlled the consequences of behavior in terms of reinforcement rate. In one schedule, subjects could maximize reinforcement rate by differentially spacing responses within a given time interval; in the other schedule, such differential response spacing had no influence on reinforcement rate. On the assumption that rate of reinforcement exerts a significant influence on DRL behavior, the two schedules were expected to maintain behaviors with measurably different characteristics. The third experiment was performed to control for other miscellaneous variables.

SCHEDULES

Both DRL schedules were arranged on a discrete trial basis to control both the onset of each timing interval and the duration between timing intervals. All intervals began with a stimulus S^P following either an S^{Δ} period or a magazine cycle. Furthermore, a limited-hold contingency was used in both schedules. Thus, a response was reinforced if it followed the onset of S^P by at least the value of the DRL but by not more than the value of the DRL plus the limited hold. The S^P was removed by the emission of a response or at the end of the limited-hold period, whichever occurred first.

Recycling Schedule

All responses in the presence of S^P were followed by the removal of S^P for 6 seconds: Reinforced responses were followed by a 6-second magazine cycle, and unreinforced responses were followed by a 6-second S^{Δ} period. The termination of the limited-hold period without a response was also followed by a 6-second S^{Δ} period. For example, in recycling DRL 18, limited hold 12 (R-DRL 18, LH 12), responses between 18 and 30 seconds after the onset of S^P were followed by a 6-second magazine cycle. Responses before 18 seconds or terminations of the 12-second, limited-hold period without a response were followed by a 6-second S^{Δ} period.

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Fixed-trial Schedule

All responses in the presence of S^P were followed by the removal of S^P for a period of time whose duration varied depending on how soon the animal responded after the onset of S^P . The time between S^P onsets was held constant. For example, in fixed-trial DRL 18, limited hold 12 (F-DRL 18, LH 12), responses between 18 and 30 seconds after the onset of S^P were followed by a 6-second magazine cycle; but S^{Δ} conditions prevailed after the cycle until 36 seconds had elapsed from the onset of S^P . Responses before 18 seconds or terminations of the 12-second, limited-hold period without a response were followed by an S^{Δ} period which lasted until 36 seconds had elapsed from the onset of S^P .

In the recycling schedule, subjects could maximize reinforcement rate by responding as often as possible in the shortest period of time after a reinforcement was set up. In the fixed-trial schedule, the reinforcement rate could not be altered by changes in the temporal distribution of responses that were emitted after reinforcements were set up.

METHOD AND PROCEDURE

Eighteen adult, male albino rats, approximately 200 $\pm$ 30 days old, were maintained at 80% of their free-feeding weights. Six subjects were used in each of the three experiments.

The experimental chamber was a box which contained a lever and a magazine for the automatic delivery of 0.1 cubic centimeter of sweetened condensed milk. The chamber and experimental cubicle were described in detail in a previous report (Herrnstein & Brady, 1958). The S^P was the illumination of two 8-watt houselights in the experimental chamber. During the S^{Δ} periods, the houselights were off; during the 6-second magazine cycles, the houselights were off but a buzzer was continuously sounded.

Responses were recorded by a series of electrical-impulse counters which tabulated the durations between the onset of S^P and the first response (S^P -R intervals). Each animal performed on a particular DRL LH schedule until its behavior was observed to generate at least 10 stable, daily, relative-frequency distributions of S^P -R intervals (no systematic variation in mode). A daily session was terminated when a subject obtained 90 reinforcements.

Table 1 presents a list of the individual subjects and the order of their experimental conditions. Note that each subject performed on both a recycling schedule and a fixed-trial schedule of the same DRL LH values. In each experiment, a particular pair of such values was examined. In Experiments I and II, half the subjects

Table 1
Design for the Three Experiments*

Experiment I			
Rats	Condition 1	Condition 2	Condition 3
1, 3, 5 2,** 4, 6	F-DRL 18, LH 12 R-DRL 18, LH 12	R-DRL 18, LH 12 F-DRL 18, LH 12	F-DRL 18, LH 12 R-DRL 18, LH 12
Experiment II			
7, 9, 11 8, 10, 12***	R-DRL 6, LH 24 F-DRL 6, LH 24	F-DRL 6, LH 24 R-DRL 6, LH 24	R-DRL 6, LH 24 F-DRL 6, LH 24
Experiment III			
13, 15, 17 14, 16, 18	F-DRL 6, LH 2 R-DRL 6, LH 2	R-DRL 6, LH 2 F-DRL 6, LH 2	

*F refers to the fixed-trial schedules and R refers to the recycling schedules.

**Because of illness, Rat 2 was eliminated after completing Condition 2.

***Rat 12 was eliminated after completing Condition 2 because of an extreme negative transfer effect.

were run in a B A B sequence of conditions and the other subjects were run in an A B A sequence. In Experiment III, half the subjects were run in a B A sequence and the other subjects were run in an A B sequence.

RESULTS

DRL 18, LH 12

Figure 1 presents combined relative-frequency distributions of S^D -R intervals for Subjects 1 through 6 of Experiment I under each condition. Each combined distribution represents the last 10 sessions for a subject under a given schedule. The solid curves represent the

fixed-trial schedule, while the dashed curves represent the recycling schedule. Note that all the distributions in Fig. 1 are characterized by low S^D -R frequencies in time intervals from 0 to 14 seconds and from 24 to 30 seconds. Most distributions derived from the recycling DRL 18, LH 12 performance were more peaked and shifted towards lower time intervals than distributions derived from the same subjects' fixed-trial DRL 18, LH 12 performance. For the exceptions, no differences between the performances on the two schedules could be discerned. The recycling distribution for Rat 2 was shifted towards shorter time intervals but was less peaked than the fixed-trial distribution. It should be pointed out, however, that this recycling distribution was the flattest distribution of any of the six rats under any condition.

Transient shifts in the distributions towards shorter time intervals were observed when Subjects 1 through 6 were switched from Condition 1 to Condition 2. Little change was observed when Condition 3 was first introduced.

In order to obtain a numerical comparison between behaviors maintained by the recycling and fixed-trial procedures, the median value of the S^D -R intervals was calculated for each daily session of each subject. The median S^D -R interval was chosen as a measure of the central tendency of the S^D -R distributions because the latter were somewhat skewed. For each subject, the final 10 median S^D -R values from a given condition were combined with the final 10 values from the successive condition. The 20 medians were then ranked without regard to source. If no overlap had occurred between the 10 medians from each condition, the sum of ranks would have been 155 for the high-rank group and 55 for the low-rank group. The difference between sums would have been 100.

Table 2 presents the sum of ranks and difference between sums for each comparison. Note that the sums of ranks from the recycling schedule were lower than the sums from the fixed-trial schedule in all but one

Fig. 1. Relative-frequency distribution of S^D -R intervals for Rats 1 through 6 of Experiment I. Solid curves represent fixed-trial DRL 18, LH 12. Dashed curves represent recycling DRL 18, LH 12. Top curves for Rats 1, 3, 4, 5, and 6: Conditions 1 and 2. Bottom curves for Rats 1, 3, 4, 5, and 6: Conditions 2 and 3.

Table 2

Comparison between Conditions 1 and 2 and between Conditions 2 and 3 in Terms of Sums of Ranks and Differences between Sums for the Final 10 Median Values of the SP-R Intervals.

	Rat 1				Rat 3				Rat 5			
	Condition 1		Condition 2		Condition 1		Condition 2		Condition 1		Condition 2	
Schedule*	F	R	R	F	F	R	R	F	F	R	R	F
Sum of Ranks	135.0	75.0	94.5	115.5	137.0	73.0	69.0	141.0	145.5	64.5	85.0	125.0
Difference	60		21		64		72		81		40	
	Rat 2				Rat 4				Rat 6			
Schedule	R	F			R	F	F	R	R	F	F	R
Sum of Ranks	67.5	142.5	—	—	110.5	99.5	143.5	66.5	63.0	147.0	146.0	64.0
Difference	75		—		11		77		84		82	

*F refers to the fixed-trial schedule; R refers to the recycling schedule.

case. The difference between sums was 60 or greater in 8 of the 11 comparisons. Therefore, in most cases, only a small degree of overlap occurred.

No probability values were assigned to the differences between sums because they would not be appropriate to these particular results. The samples are not independent because they are derived from the same animals under two different conditions and they were obtained from successive daily sessions under each condition.

DRL 6, LH 24

Figure 2 presents combined relative-frequency distributions of SP-R intervals for Subjects 7 through 12 of Experiment II under each condition. All these distributions are characterized by low SP-R frequencies in time intervals from 0 to 4 seconds and from 16 to 30 seconds. All but one of the distributions generated by the recycling DRL 6, LH 24 behavior were more peaked and shifted towards shorter time intervals than those derived from the same subjects' fixed-trial DRL 6, LH 24 behavior. The recycling distribution of Rat 12, however, was greatly shifted towards longer time intervals relative to the fixed-trial distribution.

Transient shifts in the distributions towards shorter time intervals were observed when Subjects 7, 9, and 11 were switched from the recycling to the fixed-trial schedule. Unlike these shifts and those observed in the first experiment, transient shifts in the distributions towards longer time intervals were observed when Subjects 8, 10, and 12 were switched from the fixed-trial to the recycling schedule. The shift in the case of Rat 12 was extreme, and its recycling distribution remained shifted towards longer time intervals. Little change in the distributions occurred when Condition 3 was introduced.

As in Experiment I, the comparisons between behaviors maintained by the two schedules were examined by using the sum of ranks and the difference between rank sums of median SP-R intervals. Table 3 presents this analysis for Experiment II. The sums of

ranks from the recycling schedule were lower than the sums from the fixed-trial schedule in 10 of the 11 comparisons. The difference between sums was 81 or greater in all but one instance. In six of the cases, the difference was actually 100. (This includes the case in which the difference was in the opposite direction.)

Fig. 2. Relative-frequency distributions of SP-R intervals for Rats 7 through 12 of Experiment II. Solid curves represent fixed-trial DRL 6, LH 24. Dashed curves represent recycling DRL 6, LH 24. Top curves for Rats 7 through 11: Conditions 1 and 2. Bottom curves for Rats 7 through 11: Conditions 2 and 3.

Table 3

Comparison between Conditions 1 and 2 and between Conditions 2 and 3 in Terms of Sums of Ranks and Differences between Sums for the Final 10 Median Values of the SP-R Intervals.

	Rat 8				Rat 10				Rat 12			
	Condition 1 2		Condition 2 3		Condition 1 2		Condition 2 3		Condition 1 2		Condition 2 3	
Schedule	F	R	R	F	F	R	R	F	F	R		
Sum of Ranks	147.0	63.0	56.0	154.0	145.5	64.5	55.0	155.0	55.0	155.0	—	—
Difference	84		98		81		100		100		—	
	Rat 7				Rat 9				Rat 11			
Schedule	R	F	F	R	R	F	F	R	R	F	F	R
Sum of Ranks	56.5	153.5	127.5	82.5	55.0	155.0	155.0	55.0	55.0	155.0	155.0	55.0
Difference	97		45		100		100		100		100	

Therefore, in all but one case, no overlap or only a slight overlap was obtained.

DRL 6, LH 2

Figure 3 presents combined relative-frequency distributions of SP-R intervals for Subjects 13 through 18 of Experiment III under each condition. Because of the truncation of the limited hold in the DRL 6, LH 2 schedules, SP-R intervals were tabulated and plotted in class intervals of 1 second. Relative to results obtained in Experiments I and II, differences between the distributions in Experiment III were small and less consistent.

In Experiments I and II, less than 1% of the trials on the DRL 18, LH 12 and the DRL 6, LH 24 schedules were not accompanied by a response in the presence of SP. In contrast, because of the truncation of the limited hold in the DRL 6, LH 2 schedules, from 3 to 20% of the trials in these schedules were not accompanied by a response in the presence of SP. The higher frequencies

of trials with no responses did not affect the comparison between distributions derived from the recycling DRL 6, LH 2 and the fixed-trial DRL 6, LH 2. Relative-frequency distributions of SP-R intervals based upon the total number of trials rather than the total number of responses did not alter the comparison between the fixed-trial and recycling distributions.

Transient shifts in the distributions towards shorter time intervals were observed when Rats 13 through 18 were switched from Condition 1 to Condition 2. These shifts were accompanied by a temporary increase in the number of trials in which no response was emitted in the presence of SP. The latter effect was especially marked for Rats 13, 15, and 17 which were switched from fixed-trial DRL 6, LH 2 to recycling DRL 6, LH 2.

As in Experiments I and II, the comparisons between behaviors maintained by the two schedules were examined by use of the sum of ranks and the difference between rank sums of median SP-R intervals. Table 4 presents this analysis for Experiment III. The differences between sums were generally lower than those in Experiments I and II, and the directions of differences were inconsistent. These results are consistent with the observation of smaller differences between SP-R distributions in Experiment III.

Most responses emitted in the absence of SP (SA responses) by Subjects 1 through 18 occurred in bursts following the emission of a response in the presence of SP. Responding in SA tended to decrease over experimental sessions for most subjects. Such responding was not differentially associated with the fixed-trial or recycling schedule.

DISCUSSION

The SP-R distributions obtained in this study differ in some ways from IRT distributions generated by DRL or DRL LH behavior. The IRT distributions are often characterized by modal IRT frequencies slightly below the DRL value. Frequencies of IRT's drop off rapidly in both directions from this mode (Conrad,

Fig. 3. Relative-frequency distributions of SP-R intervals for Rats 13 through 18 of Experiment III. Solid curves represent fixed-trial DRL 6, LH 2. Dashed curves represent recycling DRL 6, LH 2.

Sidman, & Herrnstein, 1958; Kelleher, Fry, & Cook, 1959; Sidman, 1955; Sidman, 1956). A second modal IRT frequency is usually observed in the earliest class interval (Conrad, Sidman, & Herrnstein, 1958; Schuster & Zimmerman, 1960; Sidman, 1955; Sidman, 1956; Zimmerman & Schuster, 1960). All SP -R distributions obtained here were characterized by the presence of a single modal SP -R value. All distributions derived from the DRL 18, LH 12 schedules had modes in the first or second SP -R interval that was reinforced. The 18-second DRL value is close to the value typically used by other investigators. Fewer responses were represented in the early portions of the DRL 18, LH 12 distributions than are usually observed in the literature. All distributions derived from the DRL 6, LH 24 and DRL 6, LH 2 schedules (except for that representing the behavior of Rat 12 on the recycling DRL 6, LH 24) were characterized by a single modal frequency in the first SP -R interval reinforced.

Procedural differences between the discrete trial schedules and ordinary DRL LH schedules could account for the differences in observed results. In the ordinary DRL LH procedures, a timing interval begins with the emission of an unreinforced response or with the termination of a reinforcement. Thus, the time between intervals and the beginning of an interval is determined exclusively by a subject's behavior. In the discrete trial procedures, the beginning of every timing interval is specified by the onset of a stimulus. Thus, every trial begins in the same way whether the subject responds before or during the limited-hold period or fails to respond before the termination of the limited-hold period. Use of the SP might account for the difference in the location of the modal value and for the diminished tendency to respond early in the timing intervals. Use of the SP certainly accounts for the absence of a mode in the earliest SP -R interval. Only responses emitted in the presence of SP were included in the SP -R distributions. Responses emitted in the absence of SP were recorded as S^A responses. As reported above, bursts of responding sometimes occurred following a response in the presence of SP . Such bursts may be similar to those often observed in ordinary DRL and DRL LH behavior. In the present experiment, these bursts were artifactually removed from the temporal-response distributions.

Anger (1956) and Conrad, Sidman, and Herrnstein (1958) have suggested that the declining frequencies of long IRT's observed in IRT distributions are related to the reduction which long IRT's would produce in the rate of reinforcement. No previous studies examined this influence of rate of reinforcement on DRL behavior.

In Experiments I and II, the number of opportunities per unit time for a subject to be reinforced on the recycling schedules was a function of the subject's own behavior. On the other hand, the number of opportunities per unit time for a subject to be reinforced on the fixed-trial schedules remained fixed by the program. The recycling DRL 18, LH 12 schedule generated temporal distributions that were often more peaked and shifted towards shorter time intervals than those generated by the fixed-trial DRL 18, LH 12 schedule. The DRL 6, LH 24 schedules in Experiment II brought such differences between the behaviors on the two schedules into sharper focus.

The differences in behavior maintained by the two schedules were relatively independent of the order of schedule presentations. This was observed in spite of the negative transfer effects that could have occurred when subjects were first transferred from a fixed trial to a recycling schedule. Experimental results in Experiments II and III indicated that such effects did exert a temporary influence on behavior; the case of Rat 12 was an extreme example.

The third experiment was undertaken as a control measure. One could argue that the relevant factor maintaining differences between the behaviors in the two schedules was the difference in length of the inter-trial interval and, concomitantly, the necessary difference in the duration of the S^A periods. The S^A periods in the recycling schedules were always 6 seconds; but the S^A periods in the fixed-trial schedules varied from trial to trial as a function of the SP -R interval. The third experiment represented a comparison between the recycling and fixed-trial schedules under conditions in which the inter-trial interval differences were retained but the interval over which reinforcement could be obtained was brief. The truncated limited hold therefore eliminated the differences between the two schedules which were related to differential rate of reinforcement consequences. Stable behaviors maintained by the two

Table 4

Comparison between Conditions 1 and 2 in Terms of Sums of Ranks and Differences between Sums for the Final 10 Median Values of the SP -R Intervals.

	Rat 13		Rat 15		Rat 17		Rat 14		Rat 16		Rat 18	
	Condition 1 2		Condition 1 2		Condition 1 2		Condition 1 2		Condition 1 2		Condition 1 2	
Schedule	F	R	F	R	F	R	R	F	R	F	R	F
Sum of Ranks	122.5	86.5	107	103	96.5	113.5	144.0	66.0	80.5	129.5	64.5	145.5
Difference	36		4		17		78		49		81	

DRL 6, LH 2 schedules were similar, and differences were slight and inconsistent.

The results of all three experiments, then, support a conclusion that reinforcement rate exercises significant control over spaced responding. However, some of the results indicate that some factor or factors besides rate of reinforcement must account for the subjects' great tendency to respond shortly after a reinforcement is set up. The temporal distributions generated by the fixed-trial schedules in Experiments I and II were most often characterized by relatively sharp peaks in the first S^p -R interval reinforced. These results were observed although no differential reinforcement in terms of reinforcement-rate consequences could occur in the fixed-trial schedules. Future research may further elucidate the critical variables controlling this aspect of spaced responding.

SUMMARY

The relationship between rate of reinforcement and spaced responding was examined in three experiments in which rats performed on two schedules of reinforcement which differentially controlled the consequences of responding in terms of the rate of reinforcement factor. Differences in behaviors maintained by the two different reinforcement schedules indicated that rate of reinforcement plays a significant role in the control of the observed behavior.

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