RESPONSE LATENCY AS A FUNCTION OF REINFORCEMENT SCHEDULE¹

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Four Ss were trained to press and hold down a telegraph key in the presence of a light. Subsequent release of the key during a tone was followed by water reinforcement. The schedule of reinforcement for key release was varied, and its effects on the latency (RT) of key release to the tone were studied. Both median RT and variability of RT were found to be inversely related to frequency of reinforcement as determined by the schedule.

In an earlier paper (Stebbins & Lanson, 1961), we have described a technique for investigating simple reaction time (RT). The design of the classical RT experiment was adapted for use with operant-conditioning procedures. A light ("ready signal") served as the discriminative stimulus (SD_1) for depression of a telegraph key (R_1). After a given interval of time (foreperiod), R_1 was followed by a tone (SD_2). Release of the key (R_2) in the presence of both tone and light was followed by water reinforcement. The latency of the key-release response to the tone was the primary dependent variable.

Stable daily RT frequency distributions were generated for water-deprived rats with this method. The RT's averaged about 200 msec. In terms of variability and skew, the distributions closely resembled those commonly found with human subjects.

The present experiment had a dual purpose. First, we developed the technique further. The fixed foreperiod of the earlier experiment was replaced with a variable foreperiod in an attempt to prevent the possibility of a temporal discrimination in the foreperiod. In addition, we imposed a more severe penalty (a longer time out) on "anticipatory" key-release responses to the tone, *i.e.*, emissions of R_2 to SD_1 before SD_2 . Second, we studied the effects

of three conditions of reinforcement (CRF, intermittent reinforcement, and extinction) on the latency of key release to the tone.

METHOD

Subjects

The subjects were four brown rats approximately 8 months old at the beginning of the experiment. Wayne Lab Blox were always available in the living cage and in the experimental chamber. Water was supplied as reinforcement during the experimental session. Free access to water was permitted for 15 min after a session. The Ss were run for 4 hr daily.

Apparatus

The experimental arrangement has been described in detail previously (Stebbins & Lanson, 1961). Briefly, the animals were trained in a sound-resistant chamber with a pedal attached to a telegraph key through one wall and a dipper mechanism that delivered 0.15 ml of water as reinforcement. A pair of neon lights with white translucent globes was located over the key. They served as SD_1 (the "ready signal"). A 4000-cps tone through a small speaker mounted between the lights was used as SD_2 . A nonaversive buzzer was mounted outside the animal's compartment, but within the sound-resistant chamber. This stimulus was presented during the time-out periods. The experimental procedures were programmed and recorded automatically. Noise from the control apparatus in an adjoining room was masked in the experimental room with white noise.

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Procedure

Conditioning. Each *S* was trained to depress the telegraph key in the presence of the two neon lights. Reinforcement followed each key release; 200 reinforcements were given under this program.

Discrimination Training. Onset of SP_1 (lights) was contingent upon 15 sec of no responding in its absence (dark). In other words, each Key press in the dark postponed SP_1 for 15 sec. In the presence of SP_1 , a key press of at least 0.5-sec duration (R_1) turned on the 4000-cps tone (SP_2) while SP_1 remained on. A key release (R_2) during both light and tone was reinforced. The response R_2 terminated the light and the tone. After reinforcement, the sequence began again with the 15-sec response-free interval. A key press in the light of less than 0.5-sec duration had no effect on the experimental conditions. Discrimination training continued until responding in the dark and responses of less than 0.5 sec in the light appeared to have reached a minimal yet stable level.

Penalty Procedure. When the discriminative behavior had stabilized, we introduced a further restriction in an attempt to extinguish key-release responses occurring in the presence of SP_1 but before SP_2 . If an "anticipatory" release response occurred in SP_1 , the lights were turned out and the nonaversive buzzer signalled a 2-min time-out period when responses had no effect on the experimental conditions. Following the time-out period, the

15-sec dark period of no responding began again.

Variable Foreperiod. When behavior became stable at the preceding stage of training, we changed the requirements for the holding response (R_1). The foreperiod is defined as the interval between the initiation of R_1 and the presentation of SP_2 . Previously, a fixed 0.5-sec foreperiod had been in effect. At this stage, we introduced a continuously variable foreperiod with a range from 0.05 to 3 sec and a mean of 1.5 sec. The relay and timing circuits programmed the sequence of foreperiods in random order. The penalty for premature key-release responses remained in effect.

Schedule Manipulation. The *Ss* were run for 40 sessions under all of the previously described contingencies. The key-release response, in the presence of the tone, was continuously reinforced (CRF). Following this training, three of the *Ss* (R-1, R-2, and R-4) were judged stable. (Judgment of stability was based on the discrimination behavior and on the day-to-day variability in the frequency distributions of RT's.) These *Ss* were then shifted to an intermittent schedule of reinforcement for key release to the tone. The fourth *S* (R-3) was maintained on the CRF schedule.

The intermittent schedule was programmed from an 11-point stepping switch. The stepper was pulsed once every 3 sec for the entire experimental session. Operation of the stepper was not in any way contingent on the animal's

Table 1
Subjects and Order of Experimental Conditions

Number of Sessions	40		14		40		9		17		1	
<i>Ss</i>												
R-1	CRF	int. (36%)	CRF	int. (36%)	CRF	int. (36%)	CRF	int. (36%)	CRF	EXT (2 sessions)		
R-2	CRF	int. (36%)	CRF	int. (36%)	CRF	int. (36%) (3 sessions)	CRF	int. (18%) (2 sessions)	CRF	EXT		
						int. (9%) (4 sessions)						
R-3	CRF	CRF	CRF	int. (36%)	CRF	int. (36%)	CRF	EXT				
R-4	CRF	int. (36%)	CRF	int. (36%)	CRF	int. (36%)	CRF	EXT				

behavior; its operation was also independent of all other experimental conditions. Of the 11 points on the stepper, 4 were connected to the reinforcement circuit. Thus, the proportion of reinforced key-release responses to the tone was 4/11, or 36 percent. In practice, for any one session, this varied between 30 and 40 percent.

After 14 sessions on this schedule, the *Ss* were returned to the CRF schedule for 40 sessions. Subsequently, all four animals were placed under the intermittent schedule for nine sessions. One *S* (R-2) was shifted further to a 2/11, or 18-percent, reinforcement schedule for two sessions and then to a 1/11, or 9-percent, reinforcement schedule for four sessions.

Finally, all *Ss* were returned again to the CRF schedule for 17 sessions, and then were extinguished for one session. One *S* (R-1) was given a second session of extinction, and the experiment was terminated. Table 1 presents a summary of the experimental conditions for each *S*.

RESULTS

Figure 1 shows the fluctuations in RT as a result of the successive changes in the reinforcement schedule. The points on the curves

Fig. 1. Median RT's in milliseconds for each of the four subjects for the final session under each reinforcement schedule.

represent the median RT's for each individual subject for the terminal session under each schedule. For example, the first point on the left for R-2 is the median latency for the final session of the first CRF period. In the curve for R-2, point A represents the median RT value on the 9-percent (1/11) schedule, and point B is the median RT value under the 18-percent (2/11) schedule; the curve is drawn through the median RT value for the 36-percent (4/11) schedule. Subject R-1 was the only subject given two extinction sessions; median RT values for both sessions are included. Subject R-3 was maintained on the CRF schedule longer than the other subjects, and was shifted to the intermittent schedule for the first time when the other subjects were being shifted to that schedule for the second time.

Figure 1 clearly demonstrates for all subjects the reversible nature of RT when the schedule is successively alternated between continuous and intermittent reinforcement. Consistent increases in median RT are evident when the schedule is changed from CRF to intermittent; conversely, RT decreases when the schedule change is in the reverse direction. The effects of only one session of extinction (for Subjects R-2, 3, 4) following CRF are extreme compared with those of the 36-percent intermittent schedule. The increase in RT in extinction is far greater than any value during the intermittent periods. For Subject R-1, a second extinction session was necessary to demonstrate a comparable effect. The data from this second session for R-1 indicate that RT is by no means stable after a single 4-hr extinction session. In fact, the data suggest not only further increases in RT but also in the rate of increase of RT (the first derivative). The notion is difficult to test since the response output by the end of the second session of extinction is close to zero.

In Fig. 2, RT (in milliseconds) is plotted as a function of the percent of key-release responses reinforced during the tone (SP_2). Thus, the point at 100 indicates CRF, and the point at zero is extinction. The plotted points at 100 and 36 are averaged from the data for CRF and intermittent reinforcement given in Fig. 1. The data from the two extinction sessions are averaged for Subject R-1. For Subject R-2, points A and B are taken directly from Fig. 1. The functions show an inverse

Fig. 2. Median RT's in milliseconds for each of the four subjects as a function of the percent of reinforced key-release responses to the tone.

relation between RT and frequency of reinforcement.

Because RT's are, for the most part, not normally distributed, the semi-interquartile range or quartile deviation (*Q*) of the RT frequency distributions, rather than the standard deviation, was used as a measure of variability of RT. In Fig. 3, the deviation values in milliseconds are plotted (as in Fig. 2) as a function of the percent of key-release responses reinforced during the tone. Values for *Q* are from the same distributions represented by medians in Fig. 1. The plotted

Fig. 3. Quartile deviation values in milliseconds for the RT frequency distributions for each subject as a function of the percent of reinforced key-release responses to the tone.

points represent averaged *Q* values from the same CRF and intermittent sessions shown in Fig. 1, and thus correspond directly to the median data of Fig. 2.

The data (Fig. 2 and 3) show that both median RT and variability of RT increase as the probability of reinforcement is decreased from 100 percent to zero percent. In addition, the data from four Ss suggest a close correlation between the median and quartile deviation values. A large shift in median RT is accompanied by a sizable shift in *Q* for R-1 (Fig. 2 and 3); minimal changes in both median and deviation value were evident for R-2 (Fig. 2 and 3).

The results of the experiment are most clearly illustrated in the RT frequency distributions in Fig. 4. Each horizontal row of graphs is for one subject. The vertical row on the left contains the distributions from the terminal session of the final CRF period. The distributions in the center row are from the last session of the final intermittent period. The distributions on the right were obtained during the extinction session. The data are grouped in 50-msec class intervals, and the interval containing the median of the distribution is shaded.

DISCUSSION

The changes in the central tendency and variability of the RT distributions between CRF and extinction confirm previous findings by the authors (Stebbins & Lanson, 1961). Furthermore, these data for latency support the results of investigators working with other properties of the operant response. Antonitis (1951) found an increase in the variability of response topography for rats from CRF to extinction. Notterman has reported sharp increases in force magnitude and variability for rats in extinction after CRF (1959) and greater force emission (and somewhat more variability) in S^A than in S^D (1960). Millenson and Hurwitz (1961), who also used rats as subjects, found that extinction following CRF produced increases in the dispersion and the central tendency of distributions of response duration.

The results of the present study indicate that, at least for latency, a schedule of reinforcement with a probability of reinforcement between CRF and extinction produces a

Fig. 4. Individual RT distributions for each subject taken from the final session of the last CRF period, the last intermittent period, and extinction.

distribution of RT's with central tendency and dispersion intermediate to that produced by CRF and extinction. An experiment by Schaefer and Steinhorst (1959) indicates the possibility of a similar relation for response duration. Rats shifted from CRF to a fixed-ratio schedule showed significant increases in response duration. Although no data were available on intrasession variability, there were marked increases in intersession variability following the change in schedule. On the other hand, Herrnstein (1961) has reported data on the topography of the pigeon's pecking response. Unlike either latency or duration, topographical variability decreased when the schedule was changed from CRF to an intermittent value (VI 3 min).

Any attempt to account for the apparent discrepancy between the effects of intermittent reinforcement upon latency and duration on the one hand and topography on the other would be premature at present. It is true that there are obvious procedural differences between the experiments. However, on the basis of the extinction data mentioned earlier, and on the basis of current behavior theory in general, it would seem that an intermittent schedule of reinforcement should generate a level of variability in behavior intermediate to that produced by extinction and regular reinforcement. An explanation of these data must necessarily await a more thorough exploration of the variable of reinforcement schedule. The use of different types of sched-

ules, in addition to a wider range of values for any one schedule, should permit a clearer understanding of the relation between schedule of reinforcement and behavioral variability.

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