THE EFFECT OF CHANGING THE SCHEDULE OF REINFORCEMENT UPON DURATION OF RESPONDING¹

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A usual datum under study in free-operant research is the rate of responding (Ferster, 1957). Of course, each response may be analyzed into smaller units, or particular dimensions. Trotter (1956a, 1956b, 1957) has divided the response in a bar-pressing situation into three components: the active time when the rat is touching the bar; eating time spent in picking up and eating food; and extra time spent in washing, resting, etc. Gilbert (1958) has investigated other dimensional properties. He lists seven, and presents cogent arguments that awareness and use of such dimensions in the analysis of the response will avoid several pitfalls of uncritically combining them.

The reduction of gross behavior to finer quantifiable units obviously would facilitate greater predictive value and better control over the organism's behavior. At this time, we wish to investigate the length of bar depression (hereafter called D). From existing evidence (Trotter, 1957), we would hypothesize that D is not consistently influenced by such variables as force required to depress the bar or length of deprivation.

The duration of bar depression may be measured in three ways: mechanically (by coupling a moving pen with the bar), electronically (by coupling a moving electric-eye diaphragm with the pen), and electrically (by letting the bar close a microswitch). The latter method was selected because of its simplicity; but this measure will yield no record of the actual time the animal was in contact with the bar. The animal may make bar presses which are not sufficient to close the microswitch. Thus, the measure obtained will constitute only those parts of the response when the pressure applied to the bar will be at least as strong as the resistance of the combined springs of the bar and the microswitch involved.

The purpose of this study is to develop a reliable method of measuring the length of depression in the bar-pressing situation, and to determine the lawfulness of this datum under varied schedules of reinforcement.

APPARATUS

Two response cages with a rat lever (Stoelting, University of Chicago design) were placed in insulated cooler chests to eliminate outside lighting and noise disturbances. Except for the translucent plastic front, the cage is made of heavy-gauge sheet aluminum. The substrate consists of stainless-steel rods spaced to pass animal waste freely. The stainless-steel lever is sprung, and protrudes 2 centimeters from the rear wall, 8.5 centimeters above the grid floor and 5.5 centimeters off the right wall. The bar is 5.5 centimeters wide and center-mounted horizontally to the lever; it travels approximately 0.4 centimeter when depressed; an 18-gram downward force upon the bar is required to activate the microswitch.

The reward lever is activated by an impulse such that it dips down and returns (by means of a counterweight) when the impulse ceases, but not before an interrupter switch has been activated at the lowest point of the reward lever. This interrupter switch serves to bring the reward lever to its lowest position, even when the duration of the bar press is too short to accomplish this. However, the interrupter switch may be excluded from the circuit, so that the bar must be depressed a certain minimal time in order for the reward lever to dip

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down deep enough to actually fill with the reinforcement liquid. The reward lever is constantly available, but interlocked so that the animal cannot push it down directly; it disappears only when the bar is depressed, either for a duration of 0.10 second or for as long as the bar is depressed. For each dip the reward lever brings up approximately 0.02 cubic centimeter of liquid.

The closing of the rat-lever microswitch activated a pen which made a continuous mark on kymograph paper moving at 50 millimeters per second.

PROCEDURE

Eleven 100-day-old male albino rats (Sprague-Dawley) were run in daily 20-minute sessions in a rat-lever cage for 30 consecutive days.² These experimental days were preceded by 4 days of pretraining, during which the response rate of the animals stabilized. The animals were watered for 20 minutes daily after experimentation. They were fed two Rockland rat diet pellets daily at approximately 6:00 p.m., which was about 5 hours after the last animal had been tested. As sporadic weight checks indicated, this diet was found to be sufficient to maintain these relatively young growing rats. No consistent record was kept of the weights of the animals, however.

During the first 10 days, all five groups were run under a continuous reinforcement (crf) schedule. After 10 days, all of the groups, except for the first, which was used as a control group, were subjected to new conditions as indicated by Table 1.

Table 1
Arrangement of Schedules of Reinforcement for 11 Rats over a 30-day Period

Group	N	Days 1-10	Days 11-20	Days 21-30
1	3	crf	crf	crf
2	2	crf	crf (shock)	crf (shock)
3	2	crf	FR 5	FR 10
4	2	crf	FR 10	FR 10
5	2	crf	crf (special)	crf (special)

Animals of Group 2 received very slight shock any time they either touched the bar or obtained reinforcement. Group 5 animals were subjected to four minor disturbances: on the 13th day of running, the switch on the control panel was turned on so that each lever press would not only depress the dipper arm but also turn on a small 20-watt electric light bulb on the ceiling of the box. This condition existed for the full 20-minute period of the 13th day. On the 17th day, the rats of Group 2 were given five 0.5-second electrical shocks through the grid during their first minute in the box. On the 21st day, each animal was dropped to the floor from a height of 3 feet, and then lifted by the tail and placed in the box. On the 25th day, each rat was placed in its home cage for 15 seconds on the platform of a running buzz saw.

The measures taken on all 10 animals were total response output as indicated by the counter on the control panel, and the length of bar depression measured in the following manner. A sample run was recorded on a fast-moving kymograph (50 millimeters per sec-

²The kind assistance of Miss B. L. Penhale in caring for the animals from birth to experimentation is gratefully acknowledged by the authors.

ond) during the 4th and 16th minutes of the experimental session. If responding did not facilitate getting an adequate sample at this time, the sample was then taken during the 5th and/or 17th minutes. A sample consisted of a chain of 10 successive responses unbroken by long pauses of no responding. The length of the pen record for each individual response of the chain was then measured by a millimeter ruler and recorded.

A record was kept of the temperature and humidity for each day. The hour of testing was constant (within ± 1 hour) from day to day.

RESULTS

In order to test the reliability of the method of sampling, a record was kept of one rat for the full 20-minute period. The animal depressed the lever 242 times for a cumulative duration of 45.25 seconds. The mean duration of bar depression computed from these figures is 0.187 second. The mean depression time, as determined by the two samples (10 responses each), was 0.188 second. This difference is not significant, and it was concluded that the sampling was reliable.

The significance of differences between Sample I and Sample II of D were analyzed by a t-test in blocks of five trials for the crf group and the FR 5 group. (See Table 2.) None of the t values is significant for the crf group. Two of the t values are significant at the 0.05 level for the FR 5 group. The implication of this will be discussed later.

Table 2
Values of t for Differences between the First and the Second Samples
of D on Blocks of Five Trials for Two Groups of Animals

Trial	crf Group		FR 5 Group	
	t	p	t	p
1-5	1.57	>0.10	0.41	>0.60
6-10	1.00	>0.30	1.00	>0.30
11-15	1.54	>0.10	2.28	<0.05
16-20	1.44	>0.10	2.41	<0.05
21-25	0.27	>0.70	1.70	>0.10
26-30	1.14	>0.20	1.80	>0.10

Note.—The df for all t is 9.

The mean D per session was compared for each of the three animals in the control group. If D of one animal was higher than that of another on one trial, the same animals maintained this relationship in the rest of the trials. A sign test was used to find the probability of these results coming about by chance. The observed differences were significant for all animals at $p < 0.001$, thus indicating a high consistency of performance.

To illustrate the fluctuations of the duration of bar pressing over the 30 experimental days, Fig. 1 presents the record of one animal on continuous reinforcement. This animal showed a somewhat higher variance in D from day to day than did other animals on crf. Nevertheless, D appears to be a rather stable value, never varying for more than 0.1 second, except on the first day.

Figure 1. Mean duration of lever depression for one male albino rat during daily 20-minute periods of regular reinforcement.

When a schedule is changed, D becomes very unstable in the transition from crf to FR 5 but returns to its normal value on about the fourth trial. However, the transition from FR 5 to FR 10, if preceded by a change from crf to FR 5, results in a much smaller change in D .

Figure 3 shows the changes in D after the schedule is changed from crf to FR 10. During the first 10 crf trials, the D stabilizes; but after the 10th trial (the new schedule was begun on the 11th trial), D increases and shows wide day-to-day fluctuations for the remaining 20 sessions.

Figure 2. Mean total response output (bar presses) and mean duration of lever depression (D) for daily 20-minute periods under three schedules of reinforcement of two male white rats.

The mean *D*'s of the daily sessions of the crf and crf (shock) groups were compared and found to be consistently lower for the shocked group ($p < 0.001$). Likewise, the response output is lower for the crf (shock) group ($p < 0.001$).

The extraneous disturbances were given to the crf (special) animals to obtain some estimate as to how strongly *D* might be influenced by interferences other than a change of schedule.

The daily mean *D* of the crf (special) group apparently showed no significant changes at the points at which the extraneous stimuli were presented. It should be remembered that disturbances of the kind used likewise also usually do not significantly influence the response rate of an animal that has settled to a steady state of responding.

Figure 3. Mean duration of bar depression for daily 20-minute periods under crf and FR 10 for two individual male white rats.

DISCUSSION

The method of sampling used to estimate *D* was extremely reliable under the present conditions. The difference between the mean of the first sample and the mean of the second sample was never significant except in two instances. (See Table 2.) The significant differences occurred when the group denoted as FR 5 was changed from crf to FR 5. This seems plausible when the increase in *D* for this group on the 11th trial is considered. In the "return to normalcy" the decline of the *D* is not only reflected in the differences from day-to-day samples, but also from the first half of the session to the second half of the same session. That is, the second sample is lower than the first in this case, because learning occurs within the limits of the 20-minute period.

The fact that the mean *D* differentiates between animals beyond chance indicates that this measure is unique to an animal, and could be due to genetic differences or could be a function of early experience. Differences in adult behavior as a function of early experiences have been found in other areas of behavior (Hall & Whiteman, 1952; Porter, Stone, & Ericksen, 1948; Scott, 1955). However, at the present, the effect early experience might have on *D* is not known.

Changed schedules of reinforcement were reflected immediately in D. A rapid increase occurred after the change to FR 5. This increase was followed by a slow drift back to "normal." However, in a more rigorous change in schedule, as from crf to FR 10, D did not indicate a return to normalcy in 20 trials. This is not to say that it never would; rather, the 20 trials may not have been sufficient under these conditions to allow a return to the previously stabilized value. It is interesting to note that the effect of the change from crf to FR 5 resulted in a marked increase of D, while the change from FR 5 to FR 10 resulted in a much smaller change. In physical terms, both of these changes are alike, so that the hypothesis that the same behavioral difference should be ascribed to them seems reasonable. Perhaps the lack of increase in D, that is, the fast return to normal D, is reminiscent of Harlow's (1949; 1950) "learning to learn" concept, which has been found useful in other areas of experimentation (Riopelle, 1953).

D reacts to a changed schedule in a different manner than does the conventional gross output measure. It reacts sooner than gross output, and does not maintain a new level but returns to a previously stabilized value in some cases.

Apparently, D is not much affected by disturbances of a minor sort, such as those used in this study.

During the time of running, temperature and humidity values in the laboratory did not vary greatly. The recorded fluctuations of temperature and humidity were not reflected either in the total response output or in our measure D.

No attempt was made to run large groups of animals in order to gain smooth curves. The experimenters were concerned with individual fluctuations of the measures used as a result of the variations in treatment. If there are wide differences in response to identical stimuli, then the relevant variables possibly are inadequately controlled. Running larger groups of animals would make the very datum to be investigated less evident. Because of the negative results on the stability of D after extraneous disturbances prior to and during running, and because of the consistency with which some animals differed from one another in the duration with which they pressed the bar, either genetic differences or early experience of sorts, rather than lack of control, may be the bases of such different modes of responding.

SUMMARY

Measures about the duration of individual depressions of a lever to obtain reinforcement and the conventional data, i.e., response rate, were taken on 11 rats in a bar-pressing apparatus.

It was found that: (1) the method of obtaining D (length of bar depression) was reliable; (2) D differentiates among animals; (3) under regular reinforcement, D is a relatively stable measure, rarely varying more than 0.1 second; (4) changes in schedule which do not show immediately in the rate/time response do show in $\bar{X}D$; (5) D becomes very unstable in the transition from crf to FR 5, but returns to its normal value on about the 4th trial; however, the transition from FR 5 to FR 10 results in a much smaller change in D and stabilizes soon after the change in schedule; (6) D of the shocked group was consistently lower than the control group; (7) under FR 10 and electric shock the D became significantly longer, varied more, and did not return to normal in 20 daily sessions; (8) disturbances such as electrical shock at the beginning of a session, dropping the animal from 3 feet to the ground, pairing a light in the box with the reinforcement, running a buzz saw beside the animal's cage before

the session, or small fluctuations in temperature and humidity did not have a significant effect on the length of D. Methodological considerations of these findings were discussed.

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