SOME TEMPORAL AND SEQUENTIAL PROPERTIES OF BEHAVIOR DURING CONDITIONING AND EXTINCTION¹

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Either directly or indirectly, measurements of operant behavior are usually in the form of probabilities of occurrence of the behavior. Response rate, resistance to extinction, percentage of correct choices, and sundry error scores are included in the class. Latency of response, commonly used where running behavior is under study and also in reaction time and avoidance paradigms, is a related subgroup in which the probabilities of occurrence are supplemented by reference to an initial zero point in time.

Although the concept of probability of occurrence has proved useful as an index to the effects of various experimental operations (Skinner, 1957), many properties of learned behavior are not well elucidated by these measures, and, furthermore, have received little theoretical or experimental treatment. For example, the probabilities of the individual-component response members cannot easily describe serial dependencies among different responses, as in the chaining of behavior. Rather, as Frick and Miller (1951) have shown, the transitional (conditional) probabilities among different response classes must be considered in order to quantify such sequential effects. Furthermore, when the variability in successive members of the same response class is of interest, measures such as response force (Notterman, 1959) and speed (Dinsmoor, 1958), spatial location of the response (Antonitis, 1951; Herrnstein, 1959), and bodily orientation at the time of the response (Antonitis, 1951; Guthrie & Horton, 1946) have been adopted.

These measures are not entirely without difficulties. Calculation of empirical estimates of transitional probabilities between two or more mutually exclusive response classes becomes exceedingly tedious when carried beyond the second or third order of approximation. All the various response-variability measures present problems of instrumentation. The present report describes the behavior of several more measures, which were observed under the relatively simple procedures of continuous reinforcement and a subsequent extinction session. The merit of these measures is that they are easily summarized quantitatively and simply instrumented, and furthermore appear to be sensitive to reinforcement operations.

METHOD

Apparatus

The basic apparatus was an experimental chamber, 9 inches wide by 9 inches long by 8 inches high, constructed of lucite plastic, with a grid floor and a detachable aluminum front wall from which a stainless steel counterbalanced lever 2 inches wide by 0.75 inch long by 0.375 inch thick projected. When depressed with a downward force of about 1.5 grams through a distance of about 1 millimeter, this lever closed a microswitch. Actuation of a solenoid dipper delivered 0.025 milliliter of Nestle's condensed milk diluted with equal parts of tap water through a 0.25-inch hole in the floor of a tray recessed in the front wall below and just to the left of the lever. If nosed open 0.5 inch with about a 5-gram force, a small, hinged transparent lucite door secured access to the milk tray and closed a microswitch. A

¹This research was supported in part by U. S. Public Health grant MF-21-60 and the Central Research Fund of the University of London.

6-volt pilot bulb illuminated the tray simultaneously with the delivery of milk, and remained on until the tray door had been opened. The entire experimental chamber was enclosed in a ventilated sound-resistant box, which also contained a 7-watt fluorescent houselight and a 6-volt doorbell.

The lever-pressing and tray-entry behaviors of the rats were automatically recorded and the reinforcement contingencies programmed by a system of relays, timers, and counters. The minimum operating times of the slowest components in this circuit were about 0.02 second. Consequently, this figure denotes the minimum lever-microswitch closure which could reliably initiate reinforcement contingencies. On five-hole paper-punched tape, a commercial electronic sequential event timer and recorder (SETAR², manufactured by R. T. Electronics, Ltd., Birmingham) recorded the times of the depression and release of the lever, and the opening of the tray door, to the nearest 0.01 second ($\pm 1\%$). In addition, cumulative records of lever-press responding were collected.

In order to exclude the possibility that apparatus noises might affect the behavior, the controlling and recording equipment was located in a separate room. In addition, white noise was present in the experimental room to mask any apparatus clicks that might penetrate the walls.

Procedure

The Ss were three mature, female hooded rats. They were placed on a 22-hour hunger rhythm for 3 weeks, and then trained to nose the transilluminated tray door open following the sound of the actuated dipper combined with a 0.33-second bell and the onset of the tray light to secure a 0.025-milliliter presentation of milk. Following this training, the lever-press response was conditioned by the method of successive approximation (Skinner, 1950). The animals were then exposed to daily 15-minute sessions under continuous reinforcement (CRF conditions, in which each lever response produced a milk delivery until inspection of cumulative records revealed no systematic between-session or within-session changes in lever rates and the behavior sequence of lever-plus-tray responses appeared to be maximally established. For Rats 7 and 9, this stabilization period was 14 sessions; for Rat 8, 10 days sufficed. At the end of this time, all three animals had received upwards of 3000 reinforcements. On the day following the last session on CRF, the animals were exposed to a single hour-long session of extinction in which conditions were exactly as they were under CRF except that the milk container was empty. Each lever press produced the 0.33-second bell, the tray light, and the empty dipper; and a subsequent tray response extinguished the tray light.

During CRF and extinction, recordings were made of the time intervals between each lever press and the subsequent release, the intervals between lever-release/tray-entry sequences, and the number of successive instances (runs) of one response class before an observed switch to the next. During CRF, data were collected only during the 2nd-12th minutes in order to avoid warmup and satiation effects.

RESULTS

Temporal Properties

Figure 1 shows frequency functions for the three rats of the inter-response times (IRT's) between lever-press (R_L) and lever-release responses obtained from the 2nd-12th minutes of

²Made available by a grant from the Royal Society.

Figure 1. Observed distributions of press-release IRT's on the final CRF session.

the final session under CRF conditions. The data are grouped in categories 0.02 second wide, and the abscissa values denote midpoints of these categories. These IRT's, or holding times, appear to be approximately symmetrically distributed for all three animals. The means and standard deviations of these distributions appear in Table 1. Although not shown here, the distributions of these press-release IRT's under CRF conditions were

Table 1

Values of Three Parameters of the Press-release IRT Frequency Functions

Subject		CRF (10 minutes)	Extinction (60 minutes)
Rat 7	n	332	167
	Mean (seconds)	.25	1.21
	SD (seconds)	.13	2.51
Rat 8	n	332	172
	Mean	.11	.47
	SD	.12	.71
Rat 9	n	324	148
	Mean	.17	.90
	SD	.06	1.13

similar in form for the several sessions preceding those shown in Fig. 1. The chief differences were nonsystematic day-to-day fluctuations in the central tendency of the functions.

Figure 2 shows the effect on these IRT's when extinction conditions are imposed. In this figure, each plotted point is the IRT (on a log scale) of a single press-release sequence. For

Figure 2. Lengths of successive press-release IRT's during the last CRF session and a subsequent 60-minute extinction session, plotted on a log scale. Each point represents a single IRT, and the solid vertical arrows mark off approximately the 5th, 10th, 15th, and 20th minutes of extinction.

comparison, the last 20 press-release IRT's on the final day of CRF are shown to the left of the vertical lines separating CRF from extinction. Extinction begins at the vertical line, and the solid arrows above the points mark the 5th, 10th, 15th, and 20th minutes, respectively, of the extinction session. (Because of a recording defect, Rat 9's first 13 press-release sequences in extinction were lost.) These graphs incidentally give a crude estimate of the rate of response during extinction, and show that between 30 and 50% of the R_L 's are emitted within the first 5 minutes. Inspection of the extinction process reveals an unmistakable upward drift in these IRT's and a possible fanning out, or increase, in their dispersion as well. A Mann-Whitney distribution-free, one-tailed³ U test applied to the first and last 10 IRT's in extinction reveals that the ranks of the later set of IRT's are significantly higher ($P < .05$) for all three rats. One-tailed F tests for homogeneity of variance for these same two IRT sets give probabilities $< .01$ for all rats that the two variances estimate the same population variance. Thus, the increase in dispersion during extinction is probably genuine.

³Previous results (Hurwitz, 1954) indicate the expected direction of the effect.

Figure 3. Comparison of observed distributions of press-release IRT's during CRF and extinction. The CRF functions are referred to the right ordinate; and extinction functions are to the left.

Figure 3 contains frequency functions of the extinction IRT's. For purposes of comparison, it contains, in addition, the CRF frequency functions of Fig. 1 on the enlarged scale appropriate to extinction. In this figure, the categories are 0.10 second wide; and, again, abscissa values are category midpoints (rounded). (For purposes of comparison, different ordinates have been used for the two sets of functions, so that the maxima of the functions for CRF and extinction approximately coincide.) The extinction frequency function is fictional in that since Fig. 2 showed that IRT's during extinction were time-dependent, Fig. 3 necessarily gives a lumped distribution that confounds time. Nevertheless, these frequency functions serve to emphasize the great differences in means and variances between CRF and extinction.

Figure 4 shows the change in still another IRT from CRF to extinction—that between lever release and an immediately-following tray entry (*i.e.*, between the R_L - R_T sequence). These R_L - R_T IRT's behave similarly to press-release times: A relatively high degree of stereotypy and small mean duration describes the data under CRF; and a drift upwards in both mean IRT and dispersion occurs in extinction. Again, the four arrows from left to right indicate the 5th, 10th, 15th, and 20th minutes of extinction. Evidently by the 5th minute, over half of the sequences that will cause these IRT's have already been emitted.

Figure 4. Length of successive R_L - R_T IRT's during last CRF session and a subsequent extinction session for a single rat, plotted on a log scale. Each point represents a single IRT, and the solid vertical arrows mark off approximately the 5th, 10th, 15th and 20th minutes of extinction.

The analogous data of Rats 7 and 9 show no systematic differences from those of Rat 8. An incidental finding of some interest is that during CRF, frequency functions of these IRT's show a form similar to the distributions of Fig. 1 and have therefore been omitted here.

Sequential Properties

In a given sequence of behavior in which the observed responses are limited to one of two classes (*e.g.*, lever presses, R_L , or tray entries, R_T , the number of successive repeated instances of one response type occurring before a change to the second class defines the length of a *run* of that type. The leftmost histogram of each of the six graphs of Fig. 5 shows the relative frequencies of the lengths of these runs for R_L (shaded) and R_T (unshaded) computed from the first 100 R_L 's and first 100 R_T 's recorded immediately after the first 2 minutes of the final CRF session. Except for the R_T runs for Rat 8, all runs for all rats are of length 1; *i.e.*, the pattern is one of strict alternation of response classes, which represents conditional probabilities $P\{R_L/R_T\}$ and $P\{R_T/R_L\}$ equal to 1. Rat 8 tended to repeat R_T about 15% of the time, but no runs longer than 2 were recorded.

An inspection of the remaining histograms of Fig. 5 shows that the change from CRF to extinction disrupts these run lengths; and the data of Fig. 6, showing the lengths of each run as a function of the ordinal run number or successive runs, also indicates this. Figure 6 shows how the alternation pattern⁴ of CRF gives way in extinction to longer and longer runs, until eventually alternation has become the exception rather than the rule.

The right-hand histograms of Fig. 5 give a composite picture of the run-length distributions computed from data obtained from the entire extinction session. Like the IRT extinction frequency functions of Fig. 3, they too are fictional in that they do not estimate the

⁴The record of Rat 7 shows R_T and R_L runs of 4 during the last 20 CRF runs, an occurrence not predicted by the CRF histograms of Fig. 5. The disparity is probably due to the beginnings of satiation, since these last 20 runs were taken during the 12th minute of the CRF session. By this time, nearly 300 reinforcements had already been amassed.

Figure 5. Histograms of the relative frequency of R_L (solid) and R_T (shaded) response runs during CRF and extinction.

probability of a given run length for any moment in the extinction process; yet they are revealing in their contrast with CRF patterns of runs.

Rate of Response

Cumulative-response curves (not reproduced here) show that the usual declines in individual rates of both lever and tray responses as extinction progressed accompanied these changes in temporal and sequential variables within the chain of learned behavior.

DISCUSSION

The results of the present study indicate that the measures of two inter-response times and length of runs of a given response class show systematic changes from conditioning to extinction. The sequential data confirm previous results by Frick and Miller (1951): As extinction progresses, not only does the frequency of the behavior decline, but also the pattern of response alternation established during conditioning gives way to longer runs of the same response, and show, further, the nature of the distributions of these runs for extinction as a whole.

The occurrence of long runs of responses in extinction provides a clue to the mechanism by which behavior is built up on fixed-ratio (Boren, 1955) or counting schedules (Mechner, 1958). In these schedules, reinforcement is most probable after a run of responses; and, as Mechner has shown, such stabilized behavior yields a symmetrical distribution of run lengths centered close to the fixed-ratio requirement. If it were not for the natural occurrence of such runs in extinction, these ratio performances which typically show such extended runs might be difficult to condition.

For a partial understanding of the observed increase in the variability of the IRT measures seen when extinction conditions are imposed after CRF, appeal must be made to re-

Figure 6. Sequential occurrence of R_1 and R_2 response runs during the final CRF session and a subsequent 60-minute extinction session. Points plotted ≥ 10 are labeled with the actual run length.

lated findings concerning increased variability of topography of response (Antonitis, 1951) and force of response (Notterman, 1959) during extinction. These studies are consistent in showing that the variability of a conditioned operant response increases markedly in extinction. Unlike topographical variation, however, an IRT cannot be considered as a property of any given response. Skinner (1950, p. 198) has pointed out that "the execution (*e.g.*, pressing a lever) may take time after the response has been initiated, but the moment of occurrence has no duration." Nevertheless, it is an empirical question whether certain or all of the IRT's in a chain of behavior might bear invariant relationships to topographical properties of given responses within the chain. In other words, force, speed, and topography at the moment a microswitch is closed probably depend partially on a certain posture adopted by the animal before the response emission. This posture in turn may depend on the topography of the particular behavior preceding it, and so forth, back through the chain. In this way, behavioral changes induced within a chain (*e.g.*, by the emotional effects of nonreinforcement) could well affect the properties of all the remaining members of the

chain. Therefore, the press-release IRT could co-vary in the same way that the peak force, speed, and topography associated with a particular lever press do, since all may be dependent on prior behavioral events. Furthermore, the holding time may be a rather special IRT in that it separates two responses whose sequential order is invariant, since they are determined by the physical requirements of the lever and not by the behavior of the animal.

Although this analysis is at present hypothetical, it need not remain so, because more refined measurements of behavior within a learned chain, including responses up to the operant upon whose emission reinforcement is made explicitly contingent, provide the test of its correctness. At the level of approximation considered to date, the IRT's observed here, as well as force and topography measures, would seem to be indices of the variability of behavior within such chains of operants. Whether such IRT's retain a simple relationship to force and topographical properties of behavior under other experimental conditions remains to be seen. The ease of instrumentation and precision in measurement of these IRT's, coupled with the present verification of at least one parallelism with force and topography, would seem to make them a candidate whose potentials are worth exploring when variability of behavior is of interest. Now that the extremes of the probability reinforcement continuum have been studied, namely, reinforcement with probabilities of 1 and 0, the question remains whether the measures studied here will differentiate among different contingencies falling between these limiting points.

The usefulness of a behavioral analysis that includes dependent variables other than frequency of response has not been emphasized in the literature of operant conditioning. Nevertheless, one application would seem to be the delineation of procedures that give identical rate effects yet vary in their effect upon other behavioral measures. In particular, the negatively accelerated rate curves characteristic of extinction (unlearning) may also be associated with satiation, fatigue, temperature change, drugs, and other diverse procedures; yet, we are reluctant to include these as cases of unlearning. At least a plausible guess is that the analysis of within-chain IRT's and response properties might provide additional dimensions on which to dissect these effects.

SUMMARY

Variations in inter-response times (IRT's) and successive runs of responses made by three rats in a lever-pressing apparatus during continuous reinforcement (CRF) and a subsequent extinction session were examined. Extinction produced an increase in dispersion and the central tendency of the IRT measures which had stabilized during CRF in approximately symmetrical distributions, and it shifted the pattern of response alternation established during conditioning to an increased probability of occurrence of long runs of the same response class. Comparison with other measures of behavior and results of other workers indicate that these measures may supplement frequency of response as convenient indices of behavior variation, and thus aid in a more complete description of behavior under diverse experimental conditions.

REFERENCES

- Antonitis, J. J. Response variability in the white rat during conditioning, extinction, and reconditioning. *J. exp. Psychol.*, 1951, **42**, 273-281.
- Boren, J. J. Response rate and resistance to extinction as functions of the fixed ratio. Unpublished doctoral dissertation, Columbia Univer., 1955.

- Dinsmoor, J. A. A device for measuring and programming the speed of execution of a single response. *J. exp. anal. Behav.*, 1958, **1**, 57-58.
- Frick, F. C., and Miller, G. A. A statistical description of operant conditioning. *Amer. J. Psychol.*, 1951, **64**, 20-36.
- Guthrie, E. R., and Horton, G. P. *Cats in a puzzle box*. New York: Reinhart, 1946.
- Herrnstein, R. J. Stereotypy of response during continuous and intermittent reinforcement. *J. exp. anal. Behav.*, 1959, **2**, 267 (Abstract).
- Hurwitz, H. M. B. Response-duration of lever pressing in the rat. *Quart. J. exp. Psychol.*, 1954, **6**, 62-71.
- Mechner, F. Probability relations within response sequences under ratio reinforcement. *J. exp. anal. Behav.*, 1958, **1**, 109-121.
- Notterman, J. M. Force emission during bar pressing. *J. exp. Psychol.*, 1959, **58**, 341-347.
- Skinner, B. F. Are theories of learning necessary? *Psychol. Rev.*, 1950, **57**, 193-216.
- Skinner, B. F. The experimental analysis of behavior, *Amer. Scient.*, 1957, **45**, 343-371.

Received July 21, 1960.