***BEHAVIOR STABILITY UNDER EXTENDED EXPOSURE TO
A TIME-CORRELATED REINFORCEMENT CONTINGENCY¹***

by

W. W. CUMMING and W. N. SCHOENFELD

COLUMBIA UNIVERSITY

"Steady state" experiments are designed to obtain complete behavioral functions from single organisms acting as their own controls, thereby avoiding certain problems involved in group-averaged functions as well as supplying information not obtainable from averaged functions. The procedure does, however, raise questions of its own which are of interest both methodologically and substantively. As an example, when an experiment requires that values of the independent variable be presented in a single ascending or descending order because of the difficulty of proceeding in any other order (e.g., Clark, 1959; Hearst, 1958; Schoenfeld, Cumming, & Hearst, 1956), there is posed not only the problem of behavior reversibility (Cumming & Schoenfeld, 1959), but also that of whether the obtained function was actually generated by the independent variable rather than merely by prolongation of training. In such studies, the experimenter inescapably faces a decision as to how long he ought continue with a given value of the independent variable before passing to a new one. In short, when an animal acts as its own control and thereby obviates the need for certain classic types of experimental control, another type of control is called for in the form of a criterion of stability in the steady state. Criteria of this sort are always arbitrary, but, even so, are rarely today made explicit by workers, or, when stated, are not accompanied by either a rationale for choosing that criterion or an estimate of its reliability.

In the literature, the term "stability" appears to refer to one or both of two things. In some places, it means that behavior is no longer changing significantly because it is close to its asymptotic value under the given conditions. In other contexts, the term seemingly refers to behavior that is highly determined by the independent variable, and, by implication, to behavior that shows minimal variability because it is not subject to random fluctuations based on other (fluctuating or transitional) variables. In any real experimental situation, however, the concern of the worker is carried by several concrete questions affecting his research design and his interpretation of obtained data. Such questions are: When could the experiment have been stopped with any desired probability that no further change in the dependent variable would have been observed? What is the actual variability of the behavior under study? What is a satisfactory rationale for defining "stability," and what is a reasonable criterion to set for accepting behavior as "stable?"

The experimental work reported here represents an exploratory examination of some of these questions by continued application of one value of an independent variable over a long period of time. For this experiment, the conditions chosen for measurements of stability were taken from values used in previous studies (Schoenfeld & Cumming, 1957; Hearst, 1958) so as to permit a comparison of the previous data with new values obtained under prolonged exposure to the schedule, and to allow evaluation of the stability criteria used in the earlier papers.

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METHOD

The subjects were six White Carneaux hen pigeons. Following arrival in the laboratory, the birds were maintained on a free-feeding regimen (diet: grain mix of 50% kaffir corn, 40% vetch, and 10% hempseed, with fresh water and grit always available) for several weeks to determine their weight norms; thereafter, each bird was reduced to 80% of its norm and held at that level throughout the experiment. Soon after weight reduction was begun, the key-pecking response was shaped for each bird and then given 50 regular reinforcements per day for 5 days before the experiment proper started. As in the related previous study (Schoenfeld & Cumming, 1957), each experimental session lasted 20 minutes, with the data of the last 15 minutes taken for treatment. The experimental room, apparatus, reinforcements (foregoing grain mix), reinforcement durations (3 seconds' access to grain mix), and other arrangements, were identical to those of the previous study. On any day, the experimental session was given the birds at the same hour, but only if each one's weight was within ± 15 grams of its 80% standard; only occasionally was it necessary to omit a day with any bird because the weight was outside of these limits and needed adjustment by either further deprivation or supplementary feeding. After each experimental session, if required, a ration (of maple peas) was given each bird to insure the bird's proper weight the next day. Response data were taken in the form of cumulative response curves, and of response rates computed for the last 15 minutes of the sessions; the latter rates were "corrected" by subtracting 3 seconds for each reinforcement obtained by the bird during the last 15 minutes and dividing the total responses during those minutes by the diminished time.

The day after the last 50 regular reinforcements had been given, each bird was put on the reinforcement schedule defined by $t^D + t^A = 30$ seconds, and $\bar{T} = 0.05$ (Schoenfeld & Cumming, 1957). This reinforcement schedule was not varied during the entire duration of the experiment, ranging from 197 to 223 daily sessions with each bird.

RESULTS AND DISCUSSION

General Trends and Variability

The corrected daily rates of responding, from the first to the last day of the experiment, are incorporated in numerical form in Table A deposited with the American Documentation Institute.² These corrected rates for each bird are graphically exhibited here in Fig. 1. It seems clear from the plots of individual data that the early stage of the experiment was characterized by daily increases in the rate of responding. This initial rise is completed in about the first 7 days by five of the six birds, the exception being Bird 27 for which the response rate continues to rise throughout the first 30 days of exposure to the schedule. Thereafter, apart from local shifts in rate, the trend in each case appears to be a gradually lowering rate throughout the course of the experiment. (The rise in rate for the last 30 days of Bird 26's record is considered by the authors to be artifactual, stemming from a malfunction in the air blower supplying this bird's cage which began to produce loud and persistent noises. Evidence confirming the artifactual source of this trend may be seen in the variability data of this animal.)

The variability in rates seems upon inspection to be of two varieties: (a) relatively abrupt changes from one level of performance to another level, and (b) day-to-day variability, or

²A 6-page table giving these data has been deposited with the American Documentation Institute. Order Document No. 6224, remitting \$1.25 for 35-mm. microfilm, or \$1.25 for 6-by-8 inch photocopies.

"noise." Thus, if the experimental days were divided into short blocks, we might find that the variability within such blocks differs from the variability between blocks. Examples of the changes in level of performance are somewhat difficult to pinpoint, since any random fluctuations in performance may take on this character (perceptually, at least). Several such shifts in Fig. 1 appear, however, to be real. Instances may be found after Day 120 for Bird 33, after Day 180 for Bird 45, after Day 100 for Bird 42, and are not absent from the record of any of the birds. We have not found it possible to correlate such shifts with any changes in the conditions of experimentation, although this possibility cannot be ruled out (e.g., humidity changes, or barometric pressure changes, which our laboratory is not equipped to measure or control). Examples of "noise" are to be found in the records of Bird 33 from Days 130 to 170, and Bird 42 from Days 60 to 90. For Birds 45, 27, and 28, this kind of variability appears to be particularly characteristic of the records immediately after the initial rise in rate.

The differences between these two kinds of variability are shown more clearly in Table 1 in which are displayed the means and standard deviations of response rates for successive blocks of 20 days. (Following the practice of the earlier experiments, the first 7 days' data are omitted from the computations reported in this table as well as in Tables 2, 3, and 4. In these tables, days have been renumbered, taking the eighth day of Table A and Fig. 1 as Day 1). Bird 33, for example, had a mean rate of 39.26 responses per minute for Days 41-60, while for Days 121-140 this rate rose to 46.11. The intra-block variability, however, stayed almost exactly the same (sigmas of 9.35 and 9.81). Comparing the same blocks for Bird 28 shows that the rate changed from 40.08 to 33.84 responses per minute, while the intra-block variability actually rose from 5.44 to 8.64. These effects are confounded, of course, if the shift in rate occurs in the middle of a block of days. The question of what size of block to take to maximize the distinction between the two kinds of variability might conveniently be explored with these data if machine computation were available, but, lacking this aid, we have not pressed the question.

When large blocks of days are taken, the variability observed combines the two varieties. To show the effects of such combination, Table 2 cumulates the data by 20-day blocks. For each bird and each block size, the mean rate in responses per minute, the standard deviation of the rate for the block, and the coefficient of variation (V) are shown. Characteristically, the variability decreases as more and more days are accreted to the base from which the calculations are made. Perhaps the most interesting result shown in Table 2 is that the relative variability (V) becomes very similar from bird to bird even though the mean rates vary widely. That is to say, the standard deviation appears to be a constant fraction of the mean rate, staying close to 19.0. (Bird 26 deviates somewhat from this general rule, the coefficient of variation of this bird approximating 25.0.) It should also be noted that the mean rate for a given bird does not change much after about the 80th day and that further accretions of daily data do not much affect the general result, so that the experiment might have been terminated at this point without altering conclusions drawn from the data.

Stability Criteria

Earlier steady-state studies (e.g., Schoenfeld, Cumming, & Hearst, 1956; Schoenfeld & Cumming, 1957) by the present authors followed the practice of continuing the exposure of an organism to a given experimental procedure until a certain performance criterion was reached, and it may be added that a similar practice has been the rule in other areas of research. Our own criterion operated in this manner: The first 7 days of exposure were al-

Figure 1. Corrected response rates per minute of the six individual birds over the entire course of the experiment.

TABLE 1
Means and Variabilities of Daily Response Rates per Minute
Taken in Successive 20-Day Blocks for Each Bird

	<i>Bird 26</i>	<i>Bird 27</i>	<i>Bird 28</i>	<i>Bird 33</i>	<i>Bird 42</i>	<i>Bird 45</i>
Days 1-20						
M	43.80	62.15	39.09	40.65	54.54	46.21
σ	8.73	23.72	13.62	6.59	6.83	17.70
V	19.9	38.2	34.8	16.2	12.5	38.3
Days 21-40						
M	42.49	88.87	39.37	35.52	56.73	46.29
σ	9.53	15.21	6.90	4.77	13.88	8.46
V	22.4	17.1	17.5	13.4	24.5	18.3
Days 41-60						
M	38.12	81.74	40.08	39.26	47.55	48.32
σ	8.13	11.16	5.44	9.35	7.90	6.64
V	21.3	13.7	13.6	23.8	16.6	13.7
Days 61-80						
M	38.39	82.81	42.08	41.85	51.04	48.52
σ	5.56	10.65	5.03	5.73	9.26	4.69
V	14.5	12.9	12.0	13.7	18.1	9.7
Days 81-100						
M	32.57	74.95	42.46	42.33	57.55	47.33
σ	6.24	11.54	4.46	5.90	4.87	7.41
V	19.2	15.4	10.5	13.9	8.5	15.7
Days 101-120						
M	26.70	75.98	35.58	39.48	42.91	48.16
σ	4.52	6.68	3.69	7.47	5.44	5.54
V	16.9	8.8	10.4	18.9	12.7	11.5
Days 121-140						
M	28.74	83.36	33.84	46.11	50.64	40.34
σ	3.96	8.47	8.64	9.81	4.55	5.39
V	13.7	10.2	25.7	21.3	9.0	13.4
Days 141-160						
M	30.68	76.64	36.71	42.89	46.08	36.49
σ	6.06	7.66	9.09	7.64	4.14	3.59
V	19.8	10.0	24.8	17.8	9.0	9.8
Days 161-180						
M	34.14	68.69	37.56	35.57	40.78	44.56
σ	9.59	6.75	6.23	5.61	4.62	11.00
V	28.1	9.8	16.6	15.8	11.3	24.7
Days 181-200			[181-190]			
M	$\left\{ \begin{array}{l} 46.43 \\ 15.92 \\ 34.3 \end{array} \right\}^*$	72.84	46.79	36.65	36.72	51.58
σ		7.34	3.72	6.00	6.87	6.05
V		10.1	8.0	16.4	18.7	11.7
Days →	[201-213]	[201-215]		[201-216]	[201-214]	[201-216]
M	63.35	68.18		37.14	41.86	48.88
σ	20.39	6.81		3.95	3.62	9.30
V	32.2	10.0		10.6	8.6	19.0

*The bracketed entries for Bird 26 covering Days 181-200 and 201-213 are of questionable validity owing to an experimental artifact (see text).

TABLE 2
Means and Variabilities of Daily Response Rates per Minute
Cumulated by 20-Day Blocks for Each Bird

	<i>Bird 26</i>	<i>Bird 27</i>	<i>Bird 28</i>	<i>Bird 33</i>	<i>Bird 42</i>	<i>Bird 45</i>
Days 1-20						
M	43.80	62.15	39.09	40.65	54.54	46.21
σ	8.73	23.72	13.62	6.59	6.83	17.70
V	19.9	38.2	34.8	16.2	12.5	38.3
Days 1-40						
M	43.14	75.51	39.23	38.09	55.63	46.25
σ	9.05	23.87	10.66	6.25	10.85	13.69
V	21.0	31.6	27.2	16.4	19.5	29.6
Days 1-60						
M	41.47	77.59	39.51	38.48	52.94	46.94
σ	9.01	20.63	9.21	7.37	10.62	11.80
V	21.7	26.6	23.3	19.2	20.1	25.1
Days 1-80						
M	40.70	78.89	40.16	39.32	52.46	47.33
σ	8.35	18.72	8.39	7.11	10.27	10.47
V	20.5	23.7	20.9	18.1	19.6	22.1
Days 1-100						
M	39.07	78.10	40.61	39.92	53.48	47.33
σ	8.59	17.54	7.80	6.97	9.64	9.90
V	22.0	22.5	19.2	17.5	18.0	20.9
Days 1-120						
M	37.01	77.75	39.78	39.85	51.72	47.47
σ	9.28	16.24	7.51	7.02	9.88	9.31
V	25.1	20.9	18.9	17.6	19.1	19.6
Days 1-140						
M	35.83	78.55	38.93	40.74	51.56	46.45
σ	9.18	15.47	7.93	7.76	9.31	9.19
V	25.6	19.7	20.4	19.0	18.1	19.8
Days 1-160						
M	35.19	78.31	38.65	41.01	50.88	45.21
σ	9.00	14.72	8.09	7.76	9.00	9.29
V	25.6	18.8	20.9	18.9	17.7	20.5
Days 1-180						
M	35.07	77.24	38.53	40.41	49.76	45.13
σ	9.05	14.37	7.90	7.73	9.19	9.46
V	25.8	18.6	20.5	19.1	18.5	21.0
Days 1-200			[1-190]			
M	$\left\{ \begin{array}{l} 36.21 \\ 10.46 \\ 28.9 \end{array} \right\}^*$	76.80	38.96	40.03	48.45	45.78
σ		13.88	7.94	7.64	9.79	9.37
V		18.1	20.4	19.1	20.2	20.5
Days →	[1-213]	[1-215]		[1-216]	[1-214]	[1-216]
M	37.86	76.20		39.82	48.02	46.01
σ	12.99	13.68		7.47	9.64	9.38
V	34.3	18.0		18.8	20.1	20.4

*The bracketed entries for Bird 26 which include Days 181-200 and 201-213 are of questionable validity owing to an experimental artifact (see text).

TABLE 3
Distribution of Criterion 6-Day Means Compared with Entire
Distribution of Successive 6-Day Means

		<i>Bird 26</i>	<i>Bird 27</i>	<i>Bird 28</i>	<i>Bird 33</i>	<i>Bird 42</i>	<i>Bird 45</i>
	N	19	27	24	24	23	24
Distribution of Experimental Criterion Data (nonoverlapping)	Mean rate (resp./min.)	36.75	77.07	39.77	39.93	47.94	45.08
	σ	10.93	8.32	5.41	5.19	8.35	6.72
	1st value:	42.09	56.33	47.21	48.09	53.85	33.89
	Day met:	20	17	20	19	19	19
Distribution of 6-Day Means (nonoverlapping)	N	35	35	31	36	34	36
	Mean rate (resp./min.)	37.57	76.74	38.80	39.84	48.36	45.99
	σ	10.29	8.29	4.69	5.11	7.84	6.68

lowed for adjustment of the bird to the new schedule; thereafter, the next 6 days and each succeeding group of 6 days were tested for stability. A 6-day period was considered to have met the stability criterion if the difference between the mean rate for the first 3 days and the rate for the second 3 days was no greater than 5% of the overall 6-day mean. If the difference between the sub-means was greater than 5% of the overall mean, another experimental day was added and similar calculations made for that day and the preceding 5 days. This process was iterated until the criterion had been met, at which time the experimental conditions were changed so that the next dependent variable value could be determined.

The present experiment permitted a check on the adequacy of this criterion since it was possible to examine those occasions on which this criterion was met and to determine what changes, if any, occurred thereafter. Table 3 shows the distribution of these 6-day means which met the stability criterion. Those means which overlapped with an earlier mean (i.e., which shared data from at least one day) have been eliminated from the table. Thus, no two of these criterion means in Table 3 could be fewer than 6 days apart. These means can be compared with a distribution of all nonoverlapping 6-day means (including noncriterion). In all cases, the first 7 days of exposure to the schedule have been excluded from these data. A comparison of the two sets of distributions shows that they are almost identical. The birds do not appear to have been more stable in those means which met the "stability criterion." A fair conclusion which may be drawn from these data is that the stability criterion selected 6-day means at random from all possible 6-day means. The stability means may, in fact, tend toward a value farther from the true mean than one would expect by chance.

The aforementioned stability criterion had been set up to select data representative of an animal's final performance, that is, behavior which was no longer changing. It was thought that a comparison of successive 3-day means would provide a way of ascertaining such equilibrium. The 5% value was chosen to assure that mean changes were small, and, hopefully, that variance of the behavior was low. Neither of these aims is realized in the present data. An examination of the first 6-day mean meeting the criterion shows that these values, which would have halted the collecting of data under the earlier procedure, do not closely conform with the final overall mean. In four of the six cases, these first criterion means are

farther than one standard deviation from the mean of the distribution of all 6-day means. Although the criterion itself tended on repeated application to select 6-day means at random, the use of the first occasion on which the criterion is met proves a bad choice in practice.

The inadequacy of our earlier criterion makes desirable a review of the rationale underlying certain types of decision in experimental work, in the present case a decision regarding behavior stability and the termination of an experimental operation. Perhaps the only positive thing to be said for our earlier criterion is that it was not subjective since that would have removed any possibility of estimating the bias in the criterion decision, whereas our criterion was quantitative and thus gave opportunity for demonstrating and estimating bias. But our criterion was of the sort of termination criteria which select data on the basis of characteristics of the data themselves. Such termination criteria take the form of specifying some behavioral characteristic and then terminating the experiment on the first occasion that the behavioral characteristic is observed. Since the use of a criterion at all implies that the behavior is undergoing change, the criterion characteristic can be said probably to represent, upon its first occurrence, an extreme value of the changing distribution of values of the particular characteristic. The same considerations apply to related termination criteria found in the literature, for example, the occurrence of one or more successive trials (say, maze runs) with 100% "correct" responses. This criterion terminates the experiment when the upper tail of the percent correct distribution reaches 100%, rather than when the mean of that distribution reaches some value. If we work backwards from any such arbitrary occurrence, we begin working with mean values and not distribution tails. As Melton (1936) has pointed out, the regression fallacy operates here to produce the artifactual appearance of an "end-spurt." An example of compounding this error is seen in the use (Underwood, 1957; also, Hayes & Pereboom, 1959) of successive criteria to exhibit the existence of multiple "end-spurts" in rote learning data. Another example of a poor termination criterion is the practice of halting extinction when an inter-response interval of a given length ("period of no responding") occurs. That this selection of one extreme of a distribution distorts the functional relation has been demonstrated by Crocetti (1952).

As we have said, however, a steady state experiment requires decision by the experimenter as to when he ought terminate exposure to a given set of conditions and proceed to another set, and for this judgment some rational grounds seem necessary. The present data allow us to draw some conclusions for the specific set of circumstances employed in this experiment. Since the birds were exposed to an experiment which may be taken practically as of "infinite" duration, it is possible to determine when their behavior came to approximate their final permanent levels. This is done in Table 4. The first three rows of values in this table show, for the first 20 experimental days, the mean rate (responses per minute), the standard error of the mean rate, and the 0.90 fiducial limits of that mean. These values should be compared with the overall mean rates shown as final entries in Table 2. Such a comparison reveals that for only three of the six birds do these fiducial limits include the overall mean values of these birds. If the behavior during the first 20 days were a good predictor of overall performance, we should, of course, expect that 90% of such fiducial limits would include the overall mean. In fact, it is not until Days 41-60 (last three rows in Table 4) that five of the six fiducial limits include the overall mean. If we take prediction of overall performance as a criterion, it is clear that it takes much longer than usually believed to reach a point of stability where values taken from steady state experiments may

TABLE 4
Fiducial Limits for Response Rates in Two 20-Day Samples at
Different Stages of Training

	<i>Bird 26</i>	<i>Bird 27</i>	<i>Bird 28</i>	<i>Bird 33</i>	<i>Bird 42</i>	<i>Bird 45</i>
Days 1-20						
Mean rate (resp./min.)	43.80	62.15	39.09	40.65	54.54	46.21
SE _M	1.94	5.31	3.05	1.47	1.53	3.96
0.90 Limits	± 3.34	± 9.13	± 5.25	± 2.53	± 2.63	± 6.81
Days 41-60						
Mean rate (resp./min.)	38.12	81.74	40.08	39.26	47.55	48.32
SE _M	1.82	2.50	1.22	2.09	1.77	1.48
0.90 Limits	± 3.13	± 4.30	± 2.10	± 3.59	± 3.04	± 2.55

The bold-face entries are fiducial limits which include the value of the mean rate for all the training days for that bird. (See Table 2 for these over-all mean values.)

justifiably be used in the determination of functions. (Of course, where we have used data from the entire course of the experiment, others might prefer taking only the last stage of performance as the estimate of overall performance.) It may be timely for research workers to consider the establishment of minimal standards of laboratory practice regarding such things as duration of exposure to training conditions before "stability" is assumed.

Extinction

Immediately following the conditioning sessions, each bird was exposed to six successive daily extinction sessions of 20-minute duration each. The cumulative response records of these sessions for each bird are shown in Fig. 2 in which the successive extinctions are separated by short diagonal strokes. It will be noted that the responding in extinction, while differing somewhat from bird to bird, nevertheless consisted largely of bursts of responses ("runs") followed by short breaks. The transition from the high rates marking the earlier sessions to the low rates of the final sessions, is in no case smooth.

The upper portion of Table 5 shows for each bird on each day of extinction, the number of responses emitted. Considering the amount of training which these birds had, extinction appears to have been a relatively rapid process.

Close examination of Fig. 2 reveals that the bursts of responding in extinction are not always at the same rate. It seemed possible to perform some analysis of this phenomenon by measurements taken from the cumulative records themselves. Photostatic copies were made of each record, and, on these, lines were drawn through each "run." Insofar as possible with only a straight edge and visual fit, care was taken to assure that the lines drawn were at the same slope as the cumulative record. Each such slope was then measured with a protractor to the nearest degree and converted into the rate of responding. For each bird this was done for as many "runs" as could be measured with accuracy. The results of this analysis are shown in the lower portion of Table 5 where, in each case, the first figure represents the number of "runs" for which such measurements were taken, while the second figure rep-

Figure 2. Cumulative response curves for the 6 days of extinction of each of the six birds. The records for the 6 days are presented continuously with short pips separating the daily records.

TABLE 5

Extinction Following Long Exposure to $[t^D + t^A]$ cycles of 30 sec., with $\bar{T} = 0.05$

Extinction Day	Number of Responses					
	Bird 26	Bird 27	Bird 28	Bird 33	Bird 42	Bird 45
1	1611	1406	987	1046	920	1528
2	1379	660	711	446	338	837
3	885	219	348	281	494	613
4	481	29	156	114	301	10
5	337	231	68	283	225	104
6	41	5	314	72	2	2
Total	4734	2550	2584	2232	2280	3094
Response Rates During "Runs" (resp./min.)						
N	45	37	41	27	22	31
M	92.71	110.88	88.12	135.87	95.35	90.51
σ	26.89	13.83	30.80	54.53	38.26	21.09

resents the mean rate of responding during "runs" in responses per minute. The final figure represents the standard deviation of the "run" rate during the whole of extinction. Examination of these data shows that there was a great deal of variability, and it was decided to attempt to relate this variability to other features of the experiment. Rank order correlations were determined between the standard deviation of "run" rates and other measures of performance for each bird. With the small number of birds involved (six), a rho of 0.82 would be significant at the 0.05 level. The correlation between the standard deviation of "run" rates in extinction, and the standard deviation of daily response rates for the entire conditioning period, approached the 0.05 significance level although in an unexpected direction, rho in this case equaling -0.714 . Aside from this possibly suggestive finding, none of the other correlations proved significant.

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