AMOUNT OF REINFORCEMENT AND FREE-OPERANT RESPONDING¹

RICHARD E. KEESEY² and J. W. KLING

BROWN UNIVERSITY

Several years ago, we began a series of studies which we hoped would allow us to specify some of the important parameters of food reinforcers. Our first aim was the development of a method which would allow investigation of these factors in the individual organism. Having the benefit of the observations of Jenkins and Clayton (1949) and Guttman (1953), we assumed that rate of response under an interval reinforcement schedule would provide a datum sensitive to differences in reinforcing stimuli. We used pigeons, because we hoped to separate such potentially important factors as amount of food *per se* and number of pecks required to obtain the food. Our early efforts were uniformly disappointing: birds were run under FI or VI conditions, with a given amount of food per reinforcement (each amount with an associated key color), until their day-to-day rates were relatively stable;³ the amount of reinforcement was then changed and the process repeated. Comparisons of the final rates achieved with each amount failed to show the expected differences, even though both amount of food and amount of consummatory responding were varied over rather wide ranges. Differences were noted, however, with four types of procedures: (1) The very first minutes of a daily session, prior to the delivery of the first one or two reinforcements, frequently produced rates correlated with the amount of food which, in past sessions, had been paired with the present key color. The discriminative stimulus of key color thus seemed to be controlling the response rate at the start of a session. (2) After many sessions in which one amount of food was used on odd-numbered days and a different amount on even-numbered days, rate differences were obtained during an extinction session in which the key colors formerly paired with each amount of food were presented alternately for 2-minute periods.⁴ (3) Although no differences between two amount-of-reinforcement conditions were observed after stable FI 2 behavior was reached, a shift to FI 4 BO 2 produced clearcut differences which then gradually disappeared over four daily 2-hour sessions on this new schedule. (4) A procedure similar to the "probe-stimulus" technique (Ferster & Skinner, 1957) showed response rates during probes that were correlated with the amount of reinforcement previously paired with the stimulus now used as a probe. In this procedure, two amounts of reinforcement, each with a correlated key color, were presented in alternate daily training sessions until day-to-day variability was relatively low. At this point, no differences between average rates for the two reinforcement conditions were seen. On subsequent sessions, the key light associated with one amount of food was inserted for 2-minute periods while the other amount with its key light was used for the remainder of the session. Probing with the larger-amount stimulus yielded an immediate increase in response rate; probing with the smaller-amount light gave an immediate decrease in rate. These probes were repeated three times daily for 8 days, always with the same results.

These preliminary experiments suggest that the stable rate of responding which results

¹Support for this research was provided by National Science Foundation Grants G-2121 and G-3859.

²Now U. S. Public Health Service Postdoctoral Fellow, Department of Psychology, U.C.L.A.

³These birds were usually run far more than the 25-30 hours beyond which Cumming and Schoenfeld (1960) found no noticeable changes in variability; yet the comment of these investigators concerning the dangers of accepting the stability criterion at face value is certainly applicable in the present experiment.

⁴Similarly, Gollub and Urban (1958) found rate differences to be greater during extinction than during training when a mult VI 3 VI 9 schedule was used.

from continued exposure to a given reinforcement schedule is relatively insensitive to manipulations of the reinforcing substance, and that such responding is largely under the control of the schedule itself. However, alterations of the procedure which allow stable responding to be disrupted provide an opportunity for response rates to reflect the relative efficacy of reinforcers. The following experiments were designed as a more adequate check of these notions.

METHOD

Subjects

Four male White Carneau pigeons were used in Experiment I and three in Experiment II. They were approximately 16 months old at the start of the experiment and were experimentally naive. Throughout the study, they were maintained at 80% of their free-feeding weights, and were fed up to this level 30 minutes after each experimental session.

Apparatus

The bird's compartment was housed in a ventilated, partially soundproofed, light-tight chamber. Sound masking was provided by the ventilating blower and a system providing white noise at approximately 80 decibels. A Gerbrands pigeon key served as the manipulum. The food cup was mounted outside the end wall of the compartment, where food was dropped into it from a rotary disc feeder. Operation of the feeder was accompanied by offset of the key light and onset of a light over the food pan. This pan light remained on for 5 seconds throughout both experiments.

Differential key colors were produced with Wratten filters. In Experiment I, Wratten Filters No. 70, 72B, 74, 75, and 76 of the monochromatic series were used. In Experiment II, No. 72B, 74, and 75 were used. The light sources and filters were arranged in a double-path optical system which allowed rapid switching from one key color to another.

Experiment I: Pretraining. All birds were magazine- and key-trained, allowed 100 responses with CRF, and then shifted immediately to VI 4. The color of the key was white, and each reinforcement consisted of 1 grain of corn. This pretraining was continued in 27 2-hour sessions, until all birds showed relatively stable day-to-day performances. Five 2-hour "base-line" sessions with the violet key color (Filter No. 76) and a quarter pea per reinforcement completed the pretraining.

Experiment I: Training. Four amounts of reinforcement were compared with the base-line (quarter pea) condition: 4 peas, 3 peas, 2 peas, and 1 pea. Commercial dried whole peas were soaked briefly in warm water, husked, and then dried. In this condition, the peas are easily divided into halves and quarters. To keep the number of pecks roughly constant from condition to condition, all amounts were delivered as four pieces of grain. Amount 1 was delivered as 4 quarter peas, Amount 2 as 4 halves, Amount 3 as 2 halves and 2 wholes, and Amount 4 as 4 whole peas. Observation of the birds revealed no noticeable variation in the time required to obtain the various amounts, and the pecking at the grains seemed quite constant from one reinforcement to the next.

The order of presentation of the experimental amounts of reinforcement was varied for each bird. The discriminative stimulus to be paired with each amount was assigned in a random manner, and was the same for all birds. These pairings were: Amount 1, Filter No. 72B (orange); Amount 2, No. 75 (blue); Amount 3, No. 74 (green); Amount 4, No. 70 (red); Base-line Amount, No. 76 (violet).

Each bird was run at the same time each day. Daily alternation of the base-line condition and one of the four experimental-amount conditions continued until responding with the experimental amount reached the criterion of stability. This criterion required five consecutive experimental-amount sessions in which the variation from the mean of these five sessions was less than $\pm 10\%$. Training with an experimental amount of food for 7 to 10 days generally sufficed to attain this standard, but performance under the base-line condition was so variable that no such criterion could be applied.⁵ It should be noted that only one amount of reinforcement was presented on any one day during this phase of the experiment.

On the day following attainment of stability, the base-line condition was used; but five "probes" were made with the stimulus previously paired with the experimental amount.

The violet key color of the base-line condition was replaced with the color appropriate to the amount of reinforcement used in the sessions which had just attained the criterion of stability. Each probe lasted 90 seconds, and was placed near the middle of a long period of nonreinforcement on the VI 4 schedule.

The day after a test session, another amount of reinforcement was used for 3 days; and then daily alternation of base-line and experimental amount was continued until the criterion of stability was met. A test session followed, and the entire procedure was repeated for the next experimental amount of reinforcement.

Experiment I: Results and Discussion. The "stable-rate" data were obtained by computing the mean responses per second for each animal for the 5 criterion days for each of the four experimental amounts of reinforcement. The means for these values are presented in Table 1A. The data for the probe-stimulus test sessions are presented in Table 1B, and were obtained by computing the mean rate on each of the test days for each bird. It is difficult to see any consistent relation between the amount of reinforcement and the stable response rate. On the other hand, the data from the probe sessions suggest rather strongly that rate under these conditions is a function of the amount of reinforcement. A treatments-by-treatments-by-subjects analysis of variance was applied to these data, and yielded a p-value of .50 for the stable-rate data and one between .10 and .20 for the probe data. The difference between the two treatments (probe method vs. stable-rate method) was significant at the .02 level. While these results suggest quite strongly that these two procedures yield different end results, they do not provide a clear demonstration that methods which interrupt the control of the reinforcement schedule will allow the parameters of reinforcement to be demonstrated in free-operant responding.

Some of the factors which added uncontrolled variance to the results now seem discernible. One of these was a serial-order effect, seen as a slight slowing of response rates during daily sessions over the 3 months of the experiment. Thus, in the stable-rate data, the order of occurrence of a particular treatment tends to be negatively correlated with the response rate. The probe-test data seem to be free from this effect, except that the very first test session gave higher rates than those of any other test for Birds 6, 7, and 8 (cf., Amounts 2, 3, and 4, respectively, in Table 1B).

A second factor seemingly influencing the results is the large amount of generalization which occurred between the key light paired with Amount 1 (orange) and that paired with Amount 4 (red). The fact that Bird 8 was run with Amount 4 before Amount 1 may account for the relatively high rate given by this animal during the Amount 1 probe-test session. All

⁵ The cases labelled "insufficient reinforcement" in Ferster and Skinner (1957) also show this marked variability.

Table 1

Responses Per Second as a Function of Amount of Reinforcement

A. Stable-rate Results					B. Probe-stimulus Results				
Bird	Amount				Amount				
	1	2	3	4	1	2	3	4	
5	1.43	1.20	1.40	1.73	1.00	1.25	2.18	3.45	
6	2.19	2.18	2.10	2.18	1.58	3.96	3.36	3.76	
7	1.85	1.90	2.35	1.83	2.57	2.98	3.98	2.64	
8	1.70	1.58	1.51	2.00	2.20	1.73	1.53	3.03	
Mean	1.79	1.72	1.84	1.94	1.84	2.48	2.76	3.22	

other birds were run in orders which placed Amount 1 earlier in the sequence than Amount 4, and the extent to which this may have influenced the results is unknown.

While this generalization might be lessened if discriminative stimuli were used more widely separated on the wavelength continuum, the serial-order effect seemed best eliminated by running all birds through every condition several times. Experiment II incorporated these changes. In place of the probe-stimulus technique, the first minute of each condition was used as a "test condition," since preliminary experiments had shown responding at the beginning of a session to be quite sensitive to reinforcement parameters. Preliminary studies also suggested the inclusion of a final extinction session during which the discriminative stimuli for all amounts were presented.

Experiment II: Training. Pretraining was the same as in Experiment I except that each bird was given only 10 daily 2-hour sessions on VI 4, with one hemp seed per reinforcement. Subsequent training consisted of daily sessions in which each bird was run under three different reinforcement conditions, 40 minutes per condition, with the order of appearance of the conditions balanced within each day. Each of the key colors (blue, green, orange) was paired with one of the amounts of reinforcement; but a different pairing was used for each animal, with the assignment made by chance. The amounts of reinforcement were 2, 4, and 8 hemp seeds per reinforcement. It should be noted that this procedure also involves differential amounts of consummatory activity, a factor which may influence responding irrespective of differences in amount of reinforcement *per se* (cf. Hall & Kling, 1960). In the present study, this combination of amount of reinforcement and amount of consummatory behavior was deliberately used to enhance differences among reinforcement conditions.

Fifteen days of this training was followed by one extinction session in which each bird was run through the three key colors; each color was present for 60 seconds, and the sequence was repeated 10 times.

Experiment II: Results and Discussion. Responding was recorded separately for each 40-minute condition and for the first minute under each condition. This procedure was based on the assumption that after a few minutes under a given condition, the reinforcement schedule would exert greater and greater control over the response rate, and that this effect would be even more noticeable as training progressed. On the other hand, the first few minutes following a shift from one condition to another should, as in the probe-stimulus

situation, allow the discriminative stimulus to be relatively more important in determining the response rate than would be the case after one or two reinforcements had again established the control of the schedule of reinforcement. For this reason, reinforcements were never programmed during the first minute of any condition.

The results tend to support this assumption. The data for the first minute of each 40-minute session clearly show the effects of the amount of reinforcement which in the past had been paired with each key color. The responding during the entire 40 minutes does not appear nearly so sensitive to the differences in the reinforcements. Figure 1 illustrates these differences in the data from the two methods.

Since there were occasional zero scores among the first-minute data, the means for each third of the training period were used. It is evident that differences attributable to reinforcement parameters are demonstrable during the first minute of each condition, that they develop rather early in the training sequence, and that they are more easily seen here than in the data from the entire 40-minute conditions. This latter fact is emphasized in Fig. 2, where the means are plotted for all animals over all sessions.

During each 40-minute period, the high rates associated with the large amount of rein-

Figure 1. A comparison of first-minute and full-session response rates as a function of three amounts of reinforcement. Open circles, 8 seeds; wedges, 4 seeds; closed circles, 2 seeds.

forcement tend to decrease. Furthermore, the response rates in the small amount of reinforcement conditions also tend to increase if they were very low at the start of the period. The over-all effect is to produce a rate at the end of each period which appears relatively insensitive to the amount of reinforcement being delivered. This phenomenon can be discerned in Fig. 2, where a comparison of the points from the 40-minute data with those of the first-minute data shows the former to be shifted toward a common response rate for the three amount-of-reinforcement conditions.

An analysis of variance applied to the first-minute data revealed neither a significant sessions effect nor a significant sessions-by-amount interaction, suggesting that the problem of serial effects was adequately controlled by the repeated running of each animal through all conditions. The analysis also supports the assumption that the first-minute scores are sensitive to reinforcement factors, a p -value of .02 being found for differences among amount conditions.

During the final session, response rates in extinction were consistently correlated with the previously used amount of reinforcement. These data are summarized in Table 2.

In general, these data suggest that a "steady state" should be avoided if parameters of positive reinforcers are to be studied with interval schedules. Instead, procedures which avoid or disrupt such stable responding seem more likely to be useful in such investigations. It seems to be a fortunate coincidence that most free-operant studies of amount of reinforcement have avoided such stable response levels through the use of relatively short daily sessions, fairly frequent shifts in procedure, and/or rather few training sessions. Some

Figure 2. The relative sensitivity of first-minute and full-session scores in reflecting amount of reinforcement conditions. The points are based on the mean rates for all birds over all sessions.

Table 2
Total Responses During Ten 1-minute Extinction Periods

Bird	Amount of Reinforcement Previously Paired with Stimulus		
	2	4	8
9	55	195	425
10	123	293	338
11	425	611	1032

of the important procedural differences are included in the over-all survey of this problem provided by Pubols (1960).

The data also suggest that remarkably little food is needed to serve as quite adequate reinforcement for the pigeon, but that there are indeed some amounts which are insufficient to maintain consistent responding. For VI 4, the quarter pea used for the base-line condition in Experiment I appeared to be "insufficient" in this sense, for the variability within and between days was greater when birds were running under the base line than under any of the other conditions.

Finally, the fact that there were no consistent differences among the final levels of responding achieved under the various reinforcement conditions of Experiment I, and that the differences were less noticeable for the entire 40 minutes than for just the first minute during Experiment II, suggests that the actual amount of reinforcement is of relatively little importance once a stable rate of responding is attained and so long as conditions of the experiment are not altered.

It is not immediately clear why extended experience with several amounts of reinforcement, each with an associated discriminative stimulus, should result in less differentiated response rates after reinforcements are delivered than early in a daily session or at the time of a procedural change when reinforcements have not yet occurred. Perhaps, the stimuli generated by responding to the reinforcements come to acquire a general, average conditioned-reinforcement value. If this is the case, it is reasonable to assume that the sample of stimuli to which the bird is responding at the start of a session should include relatively little representation of such generalized conditioned-reinforcing stimuli, with consequent greater proportional representation of stimuli associated with the key color. These key stimuli presumably have somehow come to be of differential conditioned-reinforcement value. As more and more reinforcements occur, the key-color stimuli may become a relatively smaller proportion of the stimuli controlling response rate, while the reinforcement-produced stimuli make up a greater proportion of the stimulus sample. Although this may merely be another way of saying that the bird seems to "attend" less to key color and more to reinforcement stimuli as each session proceeds, the attempt to guess at the stimuli involved may prove helpful in planning future studies of this phenomenon.

SUMMARY AND CONCLUSIONS

Amount of reinforcement was the independent variable in two experiments. One of these compared the rates achieved with each amount after a predetermined response-

stability criterion was reached with those obtained during a series of probe-stimulus tests. The second experiment compared rates at the start of each amount condition with those of the entire condition. The results support the assumption that amount of reinforcement does not yield differential response rates (at least with interval schedules) if training is continued until day-to-day variability is relatively low, but that procedures which interrupt the steady responding may allow the expected effects to be observed. It is suggested that the reinforcing events themselves may be the basis for the over-all decrease in differential responding to the various amount of reinforcement stimuli, with a general over-all level of conditioned reinforcement becoming associated with all of the different reinforcement presentations.

REFERENCES

- Cumming, W. W., and Schoenfeld, W. N. Behavior stability under extended exposure to a time-correlated reinforcement contingency. *J. exp. anal. Behav.*, 1960, **3**, 71-82.
- Ferster, C. B., and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- Gollub, L. R., and Urban, J. T. The accentuation of a rate difference during extinction. *J. exp. anal. Behav.*, 1958, **1**, 365-369.
- Guttman, N. Operant conditioning, extinction, and periodic reinforcement in relation to concentration of sucrose used as a reinforcing agent. *J. exp. Psychol.*, 1953, **46**, 213-224.
- Hall, R. D., and Kling, J. W. Amount of consummatory activity and performance in a modified T-maze. *J. comp. physiol. Psychol.*, 1960, **53**, 165-168.
- Jenkins, W. O., and Clayton, Frances L. Rate of responding and amount of reinforcement. *J. comp. physiol. Psychol.*, 1949, **42**, 174-181.
- Pubols, B. H. Incentive magnitude, learning, and performance in animals. *Psychol. Bull.*, 1960, **57**, 90-115.

Received August 12, 1960.