BEHAVIOR UNDER LARGE VALUES OF THE DIFFERENTIAL-REINFORCEMENT-OF-LOW-RATE SCHEDULE¹

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Pigeons pecked a key and rats pressed a lever for food reinforcement under large values of the differential-reinforcement-of-low-rate schedule. Each subject was tested under 10 different schedule values ranging from 1 to 45 min and was exposed to each schedule value at least twice. The mean interresponse time and mean interreinforcement time increased with the schedule value according to power functions. Response-probability functions were computed for schedule values below 20 min and showed an increase in response probability as a function of time since the last response in most cases. Mean responses per reinforcer increased as a function of schedule value for the rats, but decreased as a function of schedule value for the pigeons. The proportion of responses with interresponse times shorter than 1 sec were an increasing function of schedule value for the pigeons, but did not vary as a function of schedule value for the rats.

The differential-reinforcement-of-low rate (DRL) schedule has become one of the major schedules of reinforcement (Kramer and Rilling, 1970). The parameter of the DRL schedule (DRL value) specifies the minimum amount of time that must elapse between response n and response $n + 1$ (the interresponse time) if response $n + 1$ is to be reinforced. Most studies of behavior under the DRL schedule have used relatively small DRL values, typically 30 sec or shorter, although Malott and Cumming (1964) used a DRL value of 100 sec, and Skinner and Morse (1958) used a DRL value of 4 min, the DRL schedule serving as one component of a multiple schedule. Also, most studies of behavior under the DRL schedule have used only one DRL value, the independent variable being some other variable. The present experiment studied behavior as a function of DRL value using both rats and pigeons as subjects. The DRL value was varied from 1 to 45 min in a within-subject design. As time-based schedules typically maintain behavior under large schedule values (e.g., Dews, 1965), the DRL schedule was expected to maintain behavior under much larger DRL values than previously used.

METHOD

Subjects

Three naive homing pigeons, approximately 10 months old at the beginning of the experiment, and two naive Blue Spruce, Long Evans strain, male hooded rats, approximately seven months old at the beginning of the experiment, served as subjects. The pigeons were maintained at 75% of their free-feeding weights, the rats at 85% of their free-feeding weights.

Apparatus

The pigeons were tested in three BRS-Foringer pigeon test chambers. A panel in each test chamber had a key hole 2.5 cm in diameter located 25 cm above the floor and centered 2.5 cm to the right of the vertical center of the panel. The response key was a translucent Plexiglas paddle. The rear side of the paddle was painted flat black except for a circle 1 cm in diameter, which was centered behind the key hole. The paddle was transilluminated with white light. A force of 15 to 20 g (0.15 to 0.20 N) through an excursion of 0.1 cm was required to operate the response key. The houselight consisted of two 28-V bulbs placed behind a Plexiglas screen across the top of the panel. The reinforcer was a 3-sec presentation of mixed grain through an opening below the response key. An 85-dB white masking noise was continuously present in the test chambers.

¹We wish to thank the Computer Center of Georgia State University for providing assistance in obtaining and analyzing the data. Reprints may be obtained from W. Kirk Richardson, Psychology Department, Georgia State University, 33 Gilmer St., S.E., Atlanta, Georgia 30303.

The rats were tested in two Scientific Prototype A-100 Rodent Test Cages equipped with Scientific Prototype RL-200 retractable levers. A force of 20 to 25 g (0.20 to 0.25 N) through an excursion of 1.56 cm was required to operate the levers. The reinforcer consisted of one 45-mg Noyes rat pellet delivered in a food tray located below and to the left of the lever. A continuously burning houselight was located 10 cm above the lever in the center of the panel.

An IBM 1800 Data Acquisition System located in a separate room controlled the experiment and recorded the responses from the test chambers.

Procedure

All subjects were adapted to the test chamber, magazine trained, and pre-trained for four sessions in which every response was reinforced. Next, the subjects were trained at DRL values of 10, 15, 20, and 30 sec. Each DRL value was in effect for one session of 1 hr (10- and 15-sec values) or 2 hr (20- and 30-sec values). Next, the experiment proper began, where the DRL value was varied from 1 min to 45 min. On the first exposure to DRL values of 2 and 3 min, the subjects were trained for

80 hr under each value. At least 120 hr of training were given under each of the other conditions. The response rates were stable for at least five days before each change in DRL value. The DRL value was varied in an alternating ascending and descending sequence. The subjects were exposed to each DRL value two or three times. See Table 1 for the sequence of DRL values and the number of sessions of training under each DRL value. Beginning with the second exposure to DRL 5-min, the session duration was 12 hr; all earlier sessions had a duration of 8 hr. Finally, several sessions of extinction were administered, *i.e.*, no reinforcements were given.

Before a session began, pigeons were placed in totally dark test chambers and the rats were placed in test chambers with the levers retracted. At the start of the session, the house-lights and stimulus lights in the pigeon chambers were illuminated, and the levers were inserted into the rat chambers. At the end of a session, all lights in the pigeon chambers were extinguished, and the levers were retracted from the rat chambers.

The DRL schedule reinforced every response with an interresponse time (IRT) equal to or greater than the DRL value. The IRTs were measured as the time from the beginning of the session to the first response and thereafter as the time between two successive responses. However, when a pigeon's response was reinforced, the next IRT was measured from the end of the 3-sec reinforcement, rather than from the reinforced response.

There was a break of approximately six weeks between the tenth and eleventh session under the first exposure to the DRL 5-min schedule. Otherwise, the subjects were typically tested seven days a week.

RESULTS

The left panel of Figure 1 presents mean IRT as a function of DRL value and the right panel presents mean interreinforcement time as a function of DRL values. The points are plotted on logarithmic scales. The functions were approximately linear with mean IRT and mean interreinforcement time increasing as DRL value increased. The straight lines represent the least-squares fit of power functions to the data. The power function and the Pearson product-moment correlation coefficient

Table 1

Order and Duration of the Experimental Conditions

Ordinal Position	DRL Value (Min)	Number of Sessions
1	1	28
2	2	10
3	3	10
4	5	30
5	3	20
6	2	20
7	1	20
8	5	10
9	7	10
10	10	10
11	15	20
12	10	10
13	7	10
14	5	10
15	15	10
16	20	10
17	30	11
18	45	20
19	30	10
20	20	10
21	15	10
22	45	10
23	Extinction	15

Fig. 1. Mean IRT (left panel) and interreinforcement time (right panel) during the first, second, and third exposures as a function of DRL value with both axes as log scales. Each point is a mean of the last four or five days under a condition. The regression equations and the lines they represent are presented with each graph. The equations were computed using the method of least squares. r = product-moment correlation coefficient, T_R = mean IRT in minutes, T_s = mean interreinforcement time in minutes, t = DRL value in minutes.

(r) are presented for each subject. The correlation coefficients ranged from 0.96 to 0.99 for mean IRT and from 0.62 to 0.99 for mean interreinforcement time. The proportion of the variance (r^2) accounted for by the regression equation ranged from 92 to 97% for mean

IRT and from 39 to 97% for mean interreinforcement time. The F-ratios ranged from 251.32 to 1734.28 for mean IRT and from 12.69 to 1217.35 for mean interreinforcement time. These F-ratios were significant at the 0.01 level (1,20 df). Mean IRT and mean inter-

reinforcement time varied within a subject among the two or three exposures under a DRL value. However, the differences did not appear to be systematic and were small for mean IRT for all subjects and for mean inter-reinforcement time for the rats, relative to the effect of DRL value.

The left panel of Figure 2 presents the mean number of responses per reinforcement

as a function of DRL value. The functions for the pigeons and rats differed; responses per reinforcement decreased as DRL value increased for the pigeons, but responses per reinforcement increased as DRL value increased for the rats. The pigeons and rats also differed in absolute number of responses per reinforcement, the largest value for the rats was less than the smallest value for the pigeons.

The right panel of Figure 2 presents mean proportion of responses with IRTs shorter than 1 sec (bursting) as a function of DRL value. The rats showed a low level of bursting. Bursting did not vary as a function of DRL value for R1, and R2 showed a trend toward a decrease in bursting as DRL value was increased. The pigeons showed more bursting than did the rats under all DRL values, with the relative amount of bursting increasing as DRL value increased.

Figure 3 presents the IRT relative-frequency distributions (open circles) and response-probability (IRTs per opportunity, Anger 1956) distributions (solid circles) for the rats under the 1-, 2-, 3-, 5-, 7-, 10-, and 15-min DRL values. The relative-frequency distribution shows the proportion of responses that had IRTs within each class interval (bin), where the size of the

class interval was one twentieth of the DRL value. Thus, under different DRL values, a bin represents the same proportion (0.05) of the DRL value, but a different absolute number of seconds. Response probability is a conditional probability statistic showing the probability that a response occurs with an IRT in the class interval t to $t + x$, given that t sec have passed. The width of each class interval (bin) was one twentieth of the DRL value. The IRT relative-frequency distributions show a definite peak around the reinforced region for 1-, 2-, and 3-min DRL values. The response-probability functions increased as a function of time since the last response up to a point where the functions stopped increasing and, in some cases, decreased.

Figures 4 and 5 present the IRT relative-frequency distributions (open circles) and re-

◦-RELATIVE FREQUENCY •-RESPONSE PROBABILITY

Fig. 3. Relative-frequency and response-probability distributions for the rats. Each bin width is one twentieth of the DRL value. All IRTs to the right of the vertical, dashed line were reinforced. The right-most point in each function is either bin 29, the last response probability bin with more than 20 opportunities, or the last relative-frequency bin with at least 1% of the total responses.

sponse-probability distributions (solid circles) for the pigeons under the 1-, 2-, 3-, 5-, 7-, 10-, and 15-min DRL values. The relative-frequency distributions tended to decrease to a low stable level as a function of time since the last response. The response-probability distributions of P3 showed a high response probability in the first bin, followed by a decrease to a low level and a subsequent increase to a maximum around the reinforced region. P1 also had an increase in response probability as a function of time since the last response for all the DRL values except 1 and 3 min, where

the response-probability functions were flat. The response-probability functions of P2 tended to be flat after the first few bins at most DRL values. However, at DRL 3-min and DRL 15-min, the response-probability functions increased as a function of time since the last response. IRT relative-frequency distributions and response-probability functions are not presented for DRL values above 15 min because of the small number of responses emitted at these values.

When extinction was scheduled, the mean IRT increased. During the last five days of ex-

Fig. 4. Relative-frequency and response-probability distributions for Pigeons P1 and P2. Details same as Figure 3.

Fig. 5. Relative-frequency and response-probability distributions for Pigeon P3. Details same as Figure 3.

tionction the mean IRTs were 64, 100, 400, 150, and 69 min for P1, P2, P3, R1 and R2 respectively.

DISCUSSION

Catania (1970) studied spaced responding in pigeons under the differential-reinforcement-of-long-latencies schedule while varying the time requirement from 0.60 to 48.0 sec. The behavior was allowed to stabilize at one time value before changing to another. The differential-reinforcement-of-long-latencies schedule is a discrete trials version of DRL; the trial is initiated by illumination of the response key after an intertrial interval. A single peck terminates the trial, if the latency of the peck exceeds the time requirement, then reinforcement is delivered. Catania found that the relation between mean latency of response

and the minimum reinforced latency of response was described by a power function. Catania also examined the data from previous parametric studies of the DRL schedule in rats (Malott and Cumming, 1964) and pigeons (Staddon, 1965) and found that the relation between responding and DRL value was well described by the power function. All the studies cited above used time values below 1 min (with the exception of the highest time value in the Malott and Cumming study), the lowest time value used in the present study. Taken together, these studies, along with the present results, show that the power function is an excellent description of the relation between responding and the time requirement under spaced responding schedules over a large range of time requirements.

There is, however, an important discrepancy between Catania's results and the present ones. Catania (pp. 21 and 26) stated that the schedule lost control at time values of 36.4 and 48 sec, causing the mean response times at these time values to deviate from the power function. In fact, the data point at the 48-sec value was excluded from the computation of the power function because "control by the temporal properties of the DRL schedule was not comparable to that at shorter values". The present data show that a power function does describe mean IRT as a function of DRL value at large DRL values.

The relative-frequency and response-probability functions showed that responses do not occur randomly under large DRL values. Even under DRL 15-min, the response probability increased as a function of time since the last response. This temporal discrimination renders implausible the explanation of temporal control under these values of the DRL schedule by appealing to a response chain with the reinforced operant as the terminal component (Wilson and Keller, 1953), as the response chain would have to last 15 min. Occasional observation of the subjects often found the pigeons standing completely still with their eyes closed, and it seems unlikely that "sleeping" was part of a behavioral chain that mediated the temporal discrimination.

Although there is little support in the literature for a response chain explanation of DRL behavior, clearly manipulations affecting the probability of collateral behavior often affect responding under small values of the DRL

schedule (Laties, Weiss, and Weiss, 1969; Richardson and Loughhead, 1974). Typically, subjects (especially pigeons) are very active during the IRTs under small DRL values. Therefore, changing the probability of collateral behavior could modulate the ongoing collateral activity and indirectly affect responding on the manipulandum programmed under a DRL schedule. As there is little activity during the IRTs under large DRL values, manipulations intended to affect the probability of collateral behavior would probably have no effect on DRL behavior. Perhaps DRL behavior under large DRL values is a different "kind" than DRL behavior under small DRL values. Or perhaps they are controlled by sets of variables that only partially overlap. If so, the generality of the power law is even more striking.

Staddon (1965) and Zeiler (1972) found mean IRT to be metastable in parametric studies of DRL behavior in pigeons. The mean IRT was stable under a DRL value but was not recovered after interpolated training under other DRL values. Staddon (1965) found that mean IRT was longer under the second exposure to a DRL value. There is evidence of a similar effect in the first ascending-descending sequence (DRL 1-, 2-, 3-, and 5-min) of the present study. R1 had a longer IRT under the second exposure to each DRL value. This effect was found under DRL 3- and 5-min for P2 and under DRL 5-min for P1. The other DRL values of P1 and P2 and all four of the DRL values of P3 and R2 showed the mean IRTs to be approximately the same under the first and second exposure.

Several differences appeared between the rats and pigeons: (a) the rats had a lower response rate and higher reinforcement rate at all DRL values. (b) Bursting was at a higher level in pigeons at all DRL values; also, bursting increased as a function of DRL value in pigeons, but did not change in rats. (c) Pigeons had a higher ratio of responses to reinforcements at all DRL values; also, responses per reinforcement decreased as a function of DRL value in pigeons, but increased as a function of DRL value in rats. (d) The correlation between mean log interreinforcement time and mean log DRL value was higher in rats than in pigeons. Also, the slope of the interreinforcement-time function was steeper than the IRT function in pigeons, while the opposite rela-

tion existed for rats. These differences are consistent with the literature on DRL behavior in rats and pigeons and seem to represent differences between rats and pigeons under rather "typical" testing conditions. The variables that cause these differences have not been identified.

Staddon (1965) indicated there is reason to suspect a species difference between rat and pigeon performance under the DRL schedule. However, in view of the logical difficulty of reaching a conclusion of species difference, control by systematic variation (Bitterman, 1960) should be used to examine different types of operandum. For instance, Hemmes (1970) showed that pigeons performed more efficiently under the DRL schedule when the reinforced operant was treadle pressing. Conversely, Kramer and Rodriguez (1971) showed that rats emitted more responses per reinforcement under a DRL schedule when the operant was licking than when the operant was touching. Thus, by changing the operandum, the absolute differences in level of responding between rats and pigeons can be reduced or even reversed. If the differences in the form of the functional relationships still remained, then a species difference might be indicated.

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Received 11 December 1973.

(Final Acceptance 7 February 1974.)