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A TEST OF THE EFFECTIVENESS OF THE DIFFERENTIAL-REINFORCEMENT-OF-LOW-RATE SCHEDULE[1]

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Pigeons and rats were used in a yoked-control design that equated the reinforcement distributions of differential-reinforcement-of-low-rate and variable-interval schedules. Both a between-subjects design and a within-subjects design found response rate higher for the variable-interval schedule than for the differential-reinforcement-of-low-rate schedule, thus demonstrating the effectiveness of the differential-reinforcement-of-low-rate contingency. The interresponse-time distributions were unimodal for all subjects under the variable-interval schedule and bimodal for pigeons under the differential-reinforcement-of-low-rate schedule. The interresponse-time distributions for rats under the differential-reinforcement-of-low-rate schedule were also bimodal in three of four cases but the height of the modes at the shorter interresponse times were small in both absolute value and in relation to the height of the modes at the shorter interresponse times of the pigeons' distributions.

The reinforcement contingency of the differential-reinforcement-of-low-rate (DRL) schedule specifies differential reinforcement of interresponse times (IRTs). Any response terminating an IRT longer than the value specified by the DRL schedule is reinforced; any response terminating an IRT shorter than the value specified by the DRL schedule is not reinforced. As the name of this schedule implies, the reinforcement contingency that exists under the DRL schedule is expected to produce a low response rate. However, a low response rate alone is not proof of the effectiveness of the DRL reinforcement contingency. In order to state that the reinforcement contingency of the DRL schedule *per se* produces a low rate of responding it is necessary to compare the response rate maintained by a specific value of the DRL schedule with a second schedule that differs from the DRL schedule only by not specifying the differential reinforcement of IRTs.

The upper and lower limiting values of the DRL schedule do not require differential reinforcement of IRTs. A DRL value of infinity is a simple extinction schedule where no responses are reinforced; a DRL value of zero is a continuous reinforcement schedule where all responses are reinforced. As the value of the DRL schedule is increased above zero, some responses will meet the DRL requirement and will be reinforced, while other responses, not meeting the DRL requirement, will not be reinforced. As the DRL value is increased, two marked effects occur; the rate of reinforcement and the rate of responding decrease (Staddon, 1965). However, these same relations exist for the variable-interval (VI) schedule, which makes reinforcement available for the first response that occurs after a specified time has elapsed. This specified time is measured from the preceding reinforcement or some other environmental event and varies in length from reinforcement to reinforcement. As the value of the VI schedule is increased, there is a decrease in rate of reinforcement and rate of responding (Catania and Reynolds, 1968). This leaves the possibility that the rate of responding maintained by a DRL schedule is due only to the rate of reinforcement and the distribution of reinforcement in time. It is possible that the differential reinforcement of IRTs specified by the DRL schedule has no direct effect on behavior, *i.e.*, the subject is effectively on a VI schedule.

An experimental design that equates rate of reinforcement and interreinforcement times for a subject under a DRL schedule and a VI schedule is necessary if the effectiveness of the DRL schedule is to be empirically tested. The yoked-control design with the lead subject under a DRL schedule and the yoked-control subject under a VI schedule composed of the

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interreinforcement times generated by the lead subject meets this requirement. The present study used the yoked-control procedure to test the effectiveness of the DRL schedule in controlling response rates.

EXPERIMENT 1

METHOD

Subjects

Six naive racing homing pigeons, approximately 10 months old at the beginning of the experiment, and four 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 weight and the rats were maintained at 85% of their free-feeding weight during the experiment.

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) with 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.

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) with 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 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 computer located in a separate room controlled the experiment and recorded the responses from the test chambers.

Procedure

The pigeons were grouped into three pairs (P10-P20, P11-P21, P12-P22) and the rats were grouped into two pairs (R13-R23, R14-R24). The first member of each pair was the lead subject and the second member was the yoked control during the first 29 sessions. The lead subject received reinforcement under a DRL schedule of reinforcement: the yoked-control subject received reinforcement under a VI schedule of reinforcement where the interreinforcement intervals of the VI schedule were the same as the interreinforcement intervals of the lead subject under the DRL schedule of reinforcement. The DRL member of a yoked pair was tested first each day and the computer recorded the interreinforcement intervals. Next, the VI subject was tested; the interreinforcement intervals recorded during the DRL session were used to arrange exactly the same number and sequence of reinforcements in time as was received by the lead (DRL) subject. This procedure gave the lead (DRL) subject and the yoked (VI) subject approximately the same number of reinforcements per session as well as approximately the same distribution of reinforcements within each session.

All subjects were adapted to the test chamber, magazine trained, and pre-trained for three sessions in which every response was reinforced. Then, the experiment proper began. A DRL value of 10 sec was used during Sessions 1 and 2. Beginning with Session 3 and continuing for the remainder of the experiment the DRL value was 15 sec. The yoked-control procedure was instituted beginning with Session 1. After 27 sessions of DRL 15-sec training, the lead-yoked relationship within each pair was reversed. The subjects that previously were studied under the VI schedule now were studied under the DRL 15-sec schedule and the subjects that previously were studied under the DRL 15-sec schedule were changed to the VI schedule. After 13 sessions, the lead-yoked relationship was again reversed, returning the subjects to the original condition for 10 more sessions.

The subjects were tested for 50 min each day except for a one-day lapse between Sessions 26 and 27. Before a session began, the pigeons were placed in test chambers that were completely dark and the rats were placed in their test chambers with the levers retracted. At the start of the session, the houselights and stimulus lights in the pigeon chambers were illuminated and the rat 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 equal to or greater than the DRL requirement. 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. For the pigeons only, after a reinforced response the IRT of the next response was measured from the end of the reinforcement, not from the reinforced response.

Results

Table 1 presents the number of reinforcements, mean interreinforcement time (VI value), and the range of the interreinforcement times produced by the DRL subjects during the last five days of training under the original condition. These values were also the parameters of the VI schedules of the yoked subjects. The mean number of reinforcements obtained by a DRL subject during this five-day period was divided into the mean number of reinforcements obtained by the yoked VI subject, thus, a proportion of 1.00 would indicate that the DRL and VI subjects obtained the same number of reinforcements. The proportions of scheduled reinforcements obtained by the VI subjects were 0.99, 1.00, 1.00, 0.98, and 0.97 for VI Subjetcs P20, P21, P22, R23, and R24, respectively. The two pigeons that obtained all of the scheduled reinforcements were yoked to DRL subjects that received few reinforcements per session while the other three subjects (one pigeon, two rats) were yoked to DRL subjects that received a large number of reinforcements per session. Thus, within yoked pairs, the rates of reinforcement were almost identical for the DRL and VI schedules.

Figure 1 presents response rates for yoked pairs. Each reversal of the DRL and VI schedules resulted in a change of response rate; response rate decreased when the subject was changed from the VI to the DRL schedule and increased when the subject was changed from the DRL to the VI schedule. Comparison of the DRL and VI response rates for each yoked pair under each condition showed a lower response rate for the subject on the DRL schedule in all but two of the 15 comparisons. The two exceptions were R13-R23 in the second condition and P12-P22 in the last condition.

The IRT distributions (Figure 2) of the VI data showed a single mode in the first, second, or third second; then the functions rapidly

Table 1

Total number of reinforcements, mean interreinforcement time, and range of interreinforcement times of the lead (DRL) subject for the last five sessions of the original condition.

		Yoked Pair				
Measure	*Session*	*P10-P20*	*P11-P21*	*P12-P22*	*R13-R23*	*R14-R24*
Total Number Reinforcements	25	79	7	4	132	144
	26	92	8	1	122	143
	27	108	9	4	136	131
	28	100	4	4	130	142
	29	106	8	3	147	147
	Mean	97	7	3	133	141
Mean Interreinforcement Time (Sec)	25	38	429	750	23	21
	26	33	375	3,000	25	21
	27	28	333	750	22	23
	28	30	750	750	23	21
	29	28	375	1,000	20	20
	Mean	31	452	1,250	23	21
Interreinforcement Time Range (Sec)	25	16-124	108-1055	51-1401	15-51	15-44
	26	15-134	19-915	2704	15-90	15-66
	27	15-91	15-746	269-1526	15-63	15-95
	28	15-106	438-1680	40-1308	15-60	15-82
	29	15-74	17-1061	525-924	15-59	15-83

decreased to near zero in the sixth second. Eighty per cent, or more, of the IRTs of each VI subject were contained in the first 3-sec.

The IRT distributions of the DRL data were not as consistent among the subjects as were the VI-IRT distributions. Both rats had essentially unimodal distributions, although there was a small secondary mode in second two for R24. The principal mode was located in second 18 or 19, well above the DRL value of 15 sec.

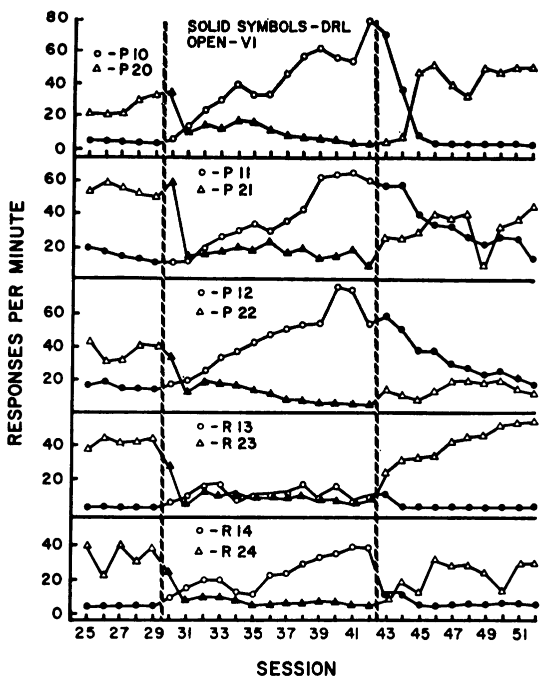

Fig. 1. Response rates across sessions. The data of each yoked pair are presented together. The solid symbols represent DRL 15-sec rates and the open symbols represent VI rates. The left panel shows the last five sessions of the original condition, the middle panel shows the first reversal, and the right panel shows the second reversal.

All pigeons had bimodal DRL-IRT distributions. One mode was located in the same region as the mode of the VI-IRT distributions, but the frequency was less than the mode of the VI-IRT distributions. For P10 the second mode was located in second 16, in the same region as the rats' modes. For the other two pigeons, the second mode was in second seven or nine, well below the DRL value of 15 sec (second 16).

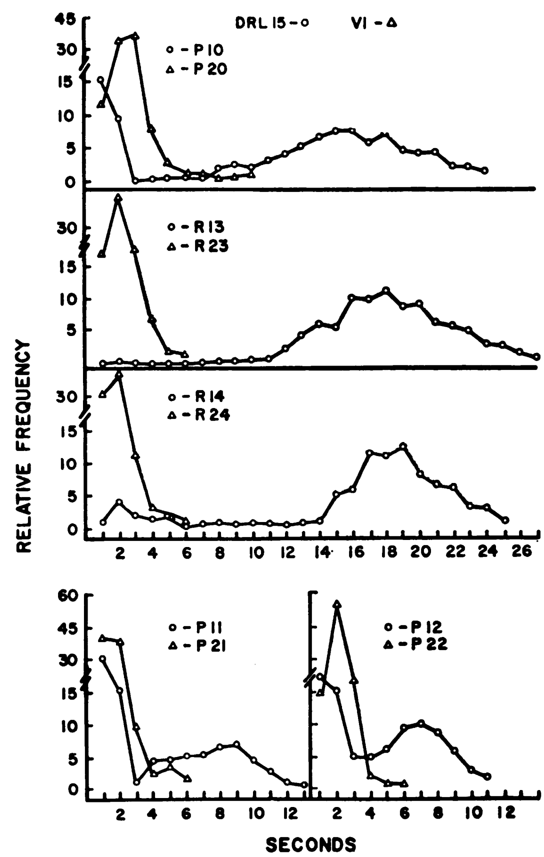

Fig. 2. Relative frequency distributions of IRTs computed from the last five days of the original condition. The IRTs are plotted in 1-sec increments with the numbers representing the nominal upper limit of each IRT, *i.e.*, the 5-sec point contains all responses with an IRT of 4.00 through 4.99 sec in duration, 16 sec is the first reinforced IRT. Percentages less than one are not plotted. Yoked pairs are plotted together; circles represent DRL 15-sec distributions and triangles represent the yoked VI distributions.

EXPERIMENT 2

The control procedure used in Experiment 1 equated rate and distribution of reinforcement between two subjects of a yoked pair, a procedure that did not allow within-subject comparisons of DRL and VI rates because the rate and distribution of reinforcement were not equated for different schedules within a single subject. Experiment 2 used a variation of the yoked-control procedure where each subject was yoked to its own behavior, *i.e.*, the rate and distribution of reinforcement generated by the subject under the DRL schedule were used to construct a VI schedule for the same subject. This procedure eliminated individual differences as a factor in the comparison of DRL and VI behavior.

Method

Subjects

Three pigeons (P20, P21, and P22) and two rats (R23 and R24) from Experiment 1 were used.

Apparatus

Same as Experiment 1.

Procedure

The subjects were trained for 10 days on a DRL 15-sec schedule. The VI schedule was constructed each day as in Experiment 1 and was recorded on IBM cards. Next, each subject was trained on a VI schedule composed of the series of interreinforcement times the subject had generated while being tested with the DRL 15-sec schedule. The subjects were given nine days of VI training. The first four sessions of VI training used the VI schedules generated during Sessions 5, 6, 7, and 8 of DRL training, in that order. The last five sessions used the VI schedule from Session 10 of DRL training. All other details were as in Experiment 1.

Results

Response rates and rates of reinforcement are presented in Figure 3. When the schedule was changed from DRL to VI, response rate increased, with all subjects showing a large increase in the first or second session of VI training. After this initial large increase, response rate slowly increased with continued training for the rats and Bird P21, but remained relatively constant for Birds P20 and P22.

During VI sessions, the IRT distributions (Figure 4) were unimodal with the mode falling in one of the first 3 sec. Eighty per cent or more of each subject's IRTs were shorter than 3 sec. The VI-IRT distributions were very similar to the distributions of Experiment 1.

All the IRT distributions for DRL had a mode in the region of second 16, the first reinforced IRT. All subjects also showed a mode in seconds one or two.

DISCUSSION

Experiment 1 compared behavior generated under a DRL 15-sec schedule and a VI sched-

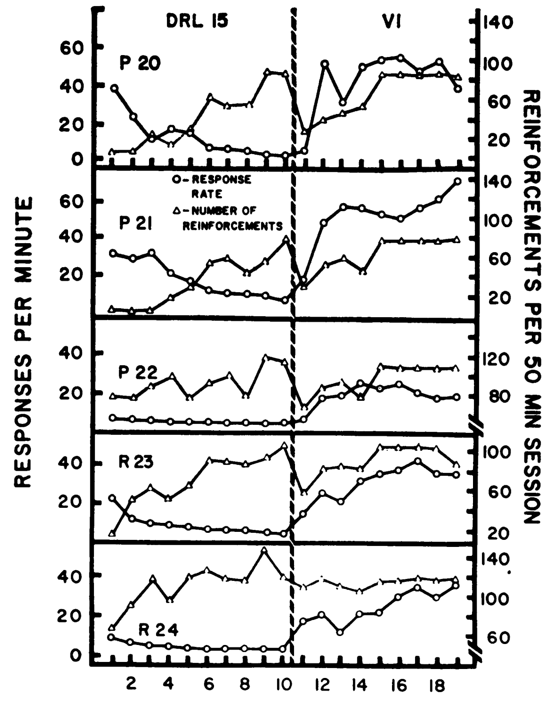

Fig. 3. Response rates and rates of reinforcement across sessions for individual subjects. The circles in the left panels show the DRL 15-sec response rates and the circles in the right panels show the VI response rates. The triangles show the number of reinforcements per session.

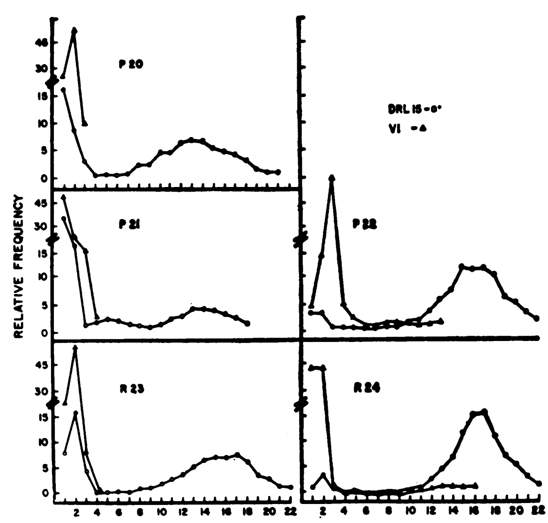

Fig. 4. Relative frequency distributions of IRTs computed from the combined data of the last five sessions under a condition. Each panel contains the DRL 15-sec (circles) and VI (triangles) distributions for one subject. Other details are the same as in Figure 2.

ule with approximately the same reinforcement distribution and found that the DRL schedule did maintain a lower response rate than the VI schedule. This showed that subjects on the DRL schedule were not controlled solely by the rate and distribution of reinforcement: the differential reinforcement of IRTs specified by the DRL was an effective variable.

The DRL and VI schedules resulted in different IRT distributions. The VI-IRT distributions were unimodal with many short IRTs; almost all IRTs were shorter than 3 sec. The DRL-IRT distributions had many IRTs much longer than the longest IRTs of the VI-IRT distributions. Three subjects (two rats, one pigeon) had modes above the DRL value of 15 sec in the region of reinforced IRTs. Two pigeons (P21 and P22) had modes below the 15-sec value and showed very few IRTs exceeding the minimum reinforced IRT. Obviously, these shorter IRT modes cannot be explained by direct reinforcement of these IRTs as the IRTs in the region of the modes were never reinforced.

The only consistent species difference observed was in the IRT distributions for DRL responses. The pigeons had a second mode at very short IRTs while the rats' distributions were essentially unimodal. Concurrently, the rats had a higher proportion of their responses in the reinforced region.

When the lead-yoked relationship was reversed, response rates changed and, in most cases, VI rates were higher than DRL rates within yoked pairs after reversal. It is not valid to make a within-subject comparison of DRL and VI rates as the reinforcement distributions were not equated for within-subject comparisons.

Experiment 2, which used within-subject comparisons, confirmed the results of Experiment 1. Each subject responded at a lower rate when reinforcement was arranged by a DRL schedule than when reinforcement was arranged by a VI schedule. The IRT distributions in Experiment 2 were of the same general form as the distributions of Experiment 1.

The yoked-control design has been criticized (Church, 1964) because a difference between the lead and yoked subjects may occur as an artifact caused by individual differences between the lead and yoked subjects. The use of a within-subject design in Experiment 2 eliminated individual differences as a factor in the comparison of the DRL and VI behavior. Since the results of Experiment 2 confirmed the results of Experiment 1, it may be assumed that the results of Experiment 1 were not artifacts due to individual differences.

Although the pigeons' VI-IRT distributions from both experiments had most of the IRTs in the first 3 sec, these distributions were not shifted to the left to the degree found in published reports of VI-IRT distributions. Both Blough and Blough (1968) and Shimp (1967) found almost all IRTs were shorter than 2 sec after training on a VI schedule, while the present study found many IRTs longer than 2 sec during VI training. This difference may be due to differences in the distribution of intervals of the VI schedules. As the VI schedule was determined by the performance under the DRL 15-sec schedule in the present experiments, the shortest possible interreinforcement interval in the VI schedule was 15 sec. In contrast, both Blough and Blough (1968) and Shimp (1967) used interreinforcement intervals much shorter than 15 sec in their VI schedules. Catania and Reynolds (1968) found that the addition of a short interval to a VI schedule can result in an increased response rate, which is consistent with the present interpretation.

Ferster and Skinner (1957, p. 460) demonstrated that the addition of a DRL contingency to a VI schedule, *i.e.,* changing the schedule to tandem VI DRL, resulted in a lower response rate in the absence of any change in rate or distribution of reinforcement. This result established the effectiveness of the DRL contingency in that situation but did not establish that the simple DRL schedule (crfdrl in Ferster and Skinner's notation) was effective. The assessment of the effectiveness of the DRL schedule requires that the VI interreinforcement times be produced by a subject on the DRL schedule and that the DRL and VI schedules be presented as simple schedules.

Kramer and Rilling (1970) pointed out the value of the yoked DRL-VI design for advancing our understanding of the DRL schedule. The procedure presented here allows a quantitative measurement of the effectiveness of the DRL contingency. Previously, the effect of the DRL contingency has typically been inferred from the degree that responding was suppressed and/or the shape of the IRT distribution, a rather subjective procedure as there was no legitimate comparison response rate or IRT distribution available.

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