INTERMITTENT REINFORCEMENT OF AN INTERRESPONSE TIME¹

DONALD M. WILKIE AND JOSEPH J. PEAR

UNIVERSITY OF MANITOBA

Rats were exposed to schedules in which reinforcement was contingent upon the emission of a 1.0- to 2.0-sec interresponse time. The rate of emission and the temporal distribution of this interresponse time was recorded. Several different contingencies between the emission of the interresponse time and reinforcement were examined. Both the rate of emission and the temporal distribution of the 1.0- to 2.0-sec interresponse time varied as a function of the schedule on which it was reinforced. This finding, which suggests that an interresponse time behaves as other operants, has implications for the analysis of conventional reinforcement schedules in terms of the differential reinforcement of interresponse times.

Different reinforcement schedules produce different rates of responding and different temporal response patterns. It has been suggested that at least some aspects of behavior generated by reinforcement schedules may be the result of the differential reinforcement of interresponse times or IRTs (*cf.* Ferster and Skinner, 1957; Malott and Cumming, 1964; Anger, 1956; Morse, 1966). Implicit in attempts to account for schedule behavior in terms of the differential reinforcement of IRTs is the assumption that IRTs behave as operants. Several lines of empirical evidence support this assumption. For example, schedules such as DRL (differential reinforcement of low rate) which selectively reinforce specific IRTs, clearly demonstrate that IRTs are sensitive to reinforcement. Also, Anger (1956) showed that the rate at which an IRT is emitted depends upon the rate of reinforcement obtained by the IRT.

Viewing IRTs as operants raises the possi-

bility that they, too, might be subject to schedule effects. If IRTs behave as other operants, both the rate at which they are emitted and their temporal distribution should be dependent upon the schedule by which they are reinforced. The present research examined this possibility.

EXPERIMENT I

In this experiment, the contingency relating a specific, arbitrary IRT class to reinforcement was varied. In different phases of the experiment, an IRT of between 1.0 and 2.0 sec was reinforced on random-interval or spaced-emission reinforcement schedules. Both the rate and the temporal distribution of the 1.0- to 2.0- sec IRTs were recorded.

METHOD

Subjects

Two adult male albino rats, obtained from the Holtzman Co., were maintained at 80% free-feeding body weight by food deprivation. Both subjects had been previously trained to respond on schedules similar to those used in the present experiment.

Apparatus

The experimental space was a Lehigh Valley Electronics Model 1316 operant conditioning chamber. The chamber contained a lever that required a force of about 16.5 g (0.162N) to operate, a 7-w houselight, and a dipper feeder used in the normally up position. The rein-

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forcer was 0.01 ml of a mixture of sweetened condensed milk and water (50% of each by volume). The reinforcer cycle, which consisted of the dipper being lowered into a reservoir of milk and then being raised, took approximately 0.5 sec. Experimental events and contingencies were arranged with solid state digital logic. A BRS-Foringer Precision Probability Unit was used to arrange the random schedules. Data were recorded on digital impulse and cumulative recorders. All scheduling and recording equipment was housed in a room separate from the one containing the experimental space.

Procedure

Both subjects were exposed, in daily 30-min sessions, to three reinforcement schedules successively. A requirement common to all three schedules was that only lever presses terminating IRTs between 1.0 and 2.0 sec were reinforced. Lever presses terminating all other IRTs were not reinforced. The schedules, in order of presentation, were:

(1) *RI*($IRT = 1.5 \pm 0.5$ sec) 5 sec. On this schedule, lever presses terminating 1.0- to 2.0-sec IRTs were reinforced once every 5 sec on the average. The time between reinforcement assignments varied randomly. This random interval (RI) schedule remained in effect for seven sessions.

(2) *DRL* ($IRT = 1.5 \pm 0.5$ sec) 4 sec. This schedule differentially reinforced a low rate of emitting the 1.0- to 2.0-sec IRTs. The 1.0- to 2.0-sec IRTs were reinforced only if the time since the preceding 1.0- to 2.0-sec IRT was greater than 4.0 sec. IRTs other than those between 1.0 and 2.0 sec had no effect on the timing of the 4.0-sec interval. If a 1.0- to 2.0-sec IRT occurred less than 4.0-sec after the last such IRT, reinforcement did not occur and the interval was restarted. If the 1.0- to 2.0-sec IRT occurred 4.0 or more seconds after the last such IRT, reinforcement occurred and the interval restarted. The amount of responding that could occur in the interval separating the two selected IRTs was not restricted. The only restriction was that a 1.0- to 2.0-sec IRT could not be reinforced if the time since the last such IRT was less than 4.0 sec. IRTs either shorter or longer than the 1.0- to 2.0-sec class could occur in the 4.0-sec interval without resetting the interval. This schedule remained in effect for 17 sessions.

(3) *RI*($IRT = 1.5 \pm 0.5$ sec) 7 sec. This schedule was similar in all respects to the *RI* ($IRT = 1.5 \pm 0.5$ sec) 5-sec schedule except that the average inter-reinforcement interval was 7 rather than 5 sec. The subjects were exposed to this schedule for six sessions.

RESULTS

The rows of Figure 1 show three measures of performance. The top row shows, for the two subjects, the overall rate of responding, in responses per second. This measure was derived by dividing the total number of lever presses during a session by the number of seconds in the session. The middle row of Figure 1 shows the rate of emitting the 1.0- to 2.0-sec IRTs. This measure is shown as the number of IRTs emitted per second. It was computed by dividing the total number of 1.0- to 2.0-sec IRTs emitted during a session by the number of seconds in the session. (It should be noted that the rate at which an IRT can be emitted has a fixed upper limit: the maximum number of 1.0- to 2.0-sec IRTs that can be emitted in a second is one.) The bottom row of Figure 1 shows the relative frequency of the 1.0- to 2.0-sec IRTs. This measure was computed by dividing the number of IRTs in the 1.0- to 2.0-sec IRT class by the total number of all IRTs emitted during a session. The columns of the figure, from left to right, show the sessions on the *RI*($IRT = 1.5 \pm 0.5$ sec) 5-sec, *DRL*($IRT = 1.5 \pm 0.5$ sec) 4-sec, and *RI*($IRT = 1.5 \pm 0.5$ sec) 7-sec schedules.

It can be seen from Figure 1 that the different schedules controlled different rates of emitting the 1.0- to 2.0-sec IRT. Both subjects emitted more than 0.6, 1.0- to 2.0-sec IRTs per second on the *RI*($IRT = 1.5 \pm 0.5$ sec) 5-sec schedule. The rate of emitting the 1.0- to 2.0-sec IRTs decreased substantially when the subjects were exposed to the *DRL*($IRT = 1.5 \pm 0.5$ sec) 4-sec schedule. Both rats emitted about 0.3, 1.0- to 2.0-sec IRTs per second on the latter schedule. This rate is close to the optimal rate of 0.25, 1.0- to 2.0-second IRTs per second for the *DRL*($IRT = 1.5 \pm 0.5$ sec) 4-sec schedule.

The decrease in the rate of emitting the 1.0- to 2.0-sec IRTs observed when the rats were shifted to the *DRL*($IRT = 1.5 \pm 0.5$ sec) 4-sec schedule suggests that the rate at which a reinforced IRT is emitted depends on the contingency between the IRT and reinforcement.

Fig. 1. Performance on the three schedules used in Experiment 1. Data for both subjects are shown. The top row shows the overall rate of lever pressing. The middle row shows the rate of emitting the 1.0- to 2.0-sec IRT. The bottom row shows the relative frequency of the 1.0- to 2.0-sec IRTs. The columns represent the three schedules: RI(IRT = 1.5 ± 0.5 sec) 5-sec (first column), DRL(IRT = 1.5 ± 0.5 sec) 4-sec (second column), and RI(IRT = 1.5 ± 0.5 sec) 7-sec (third column).

The evidence on this point is, however, not unequivocal because the rate of reinforcement on the DRL (IRT = 1.5 ± 0.5 sec) 4-sec schedule was slightly lower than on RI(IRT = 1.5 ± 0.5 sec) 5-sec schedule (see Table 1).

Following the sessions on the DRL(IRT = 1.5 ± 0.5 sec) 4-sec schedule, the subjects were exposed to a RI(IRT = 1.5 ± 0.5 sec) 7-sec schedule. An average interreinforcement interval of 7 sec was chosen so as to match approximately the rate of reinforcement obtained on the DRL(IRT = 1.5 ± 0.5 sec) 4-sec schedule. Despite the fact that the RI(IRT = 1.5 ± 0.5 sec) 7-sec schedule provided about the

same rate of reinforcement as the DRL(IRT = 1.5 ± 0.5 sec) 4-sec schedule, the former sched-

Table 1

The mean number of reinforcements obtained per minute on the different schedules in Experiment 1. The means are based on the last five sessions on a schedule.

Schedule	Average Reinforcements per Minute	
	Rat 62	Rat 63
RI(IRT = 1.5 ± 0.5 sec) 5 sec	12.80	11.68
DRL(IRT = 1.5 ± 0.5 sec) 4 sec	8.55	7.74
RI(IRT = 1.5 ± 0.5 sec) 7 sec	7.03	7.73

ule controlled a considerably higher rate of emitting the 1.0- to 2.0-sec IRTs.

Figure 1 also shows the overall rate of lever pressing on the three schedules. Both random-interval schedules controlled a higher overall rate of lever pressing than did the DRL(IRT = 1.5 ± 0.5 sec) 4-sec schedule. This decrease in overall response rate is interesting because it is not a necessary consequence of the DRL(IRT = 1.5 ± 0.5 sec) 4-sec schedule. Because of the manner in which the DRL(IRT = 1.5 ± 0.5 sec) 4-sec schedule was arranged, either of two behavior patterns could allow the required interval to progress, namely, emitting IRTs briefer than 1.0 sec (which could lead to an increased overall rate of responding) or emitting IRTs longer than 2.0 sec (which could lead to a decreased overall rate of responding).

Also shown in Figure 1 is the relative frequency of the 1.0- to 2.0-sec IRTs. The relative frequency of the 1.0- to 2.0-sec IRTs was lower on the DRL(IRT = 1.5 ± 0.5 sec) 4-sec schedule than on the random-interval schedules.

The decrease in the relative frequency of 1.0- to 2.0-sec IRTs observed on the DRL(IRT = 1.5 ± 0.5 sec) 4-sec schedule was due primarily to a reduction in the number of 1.0- to 2.0-sec IRTs that were emitted, rather than to an increase in the frequency of other IRTs.

The rate at which an operant is emitted is one aspect of a schedule performance. Another aspect is the distribution of times between successive emissions of the operant. Figure 2 shows the relative frequency distributions, in class intervals of 1 sec, of the times between successive emissions of the 1.0- to 2.0-sec IRT for the different reinforcement schedules. This figure depicts what might be called an "inter-(1.0 sec $\leq$ IRT $\leq$ 2.0 sec)-time" distribution.

Under both RI(IRT = 1.5 ± 0.5 sec) schedules, the mode of the distribution of times between successive emissions of the 1.0- to 2.0-sec IRT was between 1.0 and 2.0 sec. Under the DRL(IRT = 1.5 ± 0.5 sec) 4-sec schedule, the distribution was bimodal: one mode, although less pronounced, still occurred in the 1.0 to 2.0 sec region; a second mode occurred in the 4 to

Fig. 2. The relative frequency distribution of times between successive 1.0- to 2.0-sec IRTs for the three schedules used in Experiment 1. Cell numbers represent the lower limit of each cell in seconds. Data are from the last three [RI(IRT = 1.5 ± 0.5 sec) schedules] or last nine [DRL(IRT = 1.5 ± 0.5 sec) 4-sec schedule] sessions on a schedule.

6 sec region. This second mode on the DRL (IRT = 1.5 ± 0.5 sec) 4-sec schedule reflects the spacing required between successive emissions of the 1.0- to 2.0-sec IRT. These data suggest that the temporal distribution of IRTs as well as the rate of emission of the IRTs depends upon the contingency relating the emission of the IRT to reinforcement.

Some representative cumulative records of emission of 1.0- to 2.0-second IRTs on the DRL (IRT = 1.5 ± 0.5 sec) 4-sec and RI (IRT = 1.5 ± 0.5 sec) 7-sec schedules are shown in Figure 3. In these records, emissions of the 1.0- to 2.0-sec IRTs (*not* responses) are cumulated over time. Slash marks indicate the occurrence of reinforcement. It should be noted again that the maximum rate at which the 1.0- to 2.0-sec IRT could be emitted is one per second. The most obvious difference between the records is the lower rate of emitting 1.0- to 2.0-sec IRTs on the DRL (IRT = 1.5 ± 0.5 sec) 4-sec schedule. Another point of interest is the similarity between performance on the RI (IRT = 1.5 ± 0.5 sec) and DRL (IRT = 1.5 ± 0.5 sec) schedules and performance on simple random- or variable-interval and DRL schedules. In several aspects the performances are similar. On the RI (IRT = 1.5 ± 0.5 sec) schedules, the 1.0- to 2.0-sec IRTs were emitted at a more-or-less constant rate with few pauses after reinforcement. A similar response pattern is commonly observed on simple variable- or random-interval schedules (*e.g.*, Ferster and Skinner, 1957). On the DRL (IRT = 1.5 ± 0.5 sec) 4-sec schedule it is interesting to note that the subjects sometimes tended to emit the 1.0- to 2.0-sec IRTs in "bursts". Similar behavior is often observed on simple DRL schedules (*e.g.*, Sidman, 1956). The tendency, apparent in the present records, for reinforcements to occur in sequences or groups has also been noted with simple DRL schedules (*e.g.*, Kelleher, Fry and Cook, 1959).

DISCUSSION

The results of Experiment I suggest that the behavior of a reinforced IRT class is in many ways similar to the behavior of simpler operants such as lever pressing or key pecking. In particular, the results suggest that both the frequency at which an IRT is emitted and the temporal pattern of emission of the IRT is dependent upon the contingency between the IRT and reinforcement. Evidence on this

point comes from the part of the experiment where reinforcement frequency was held constant and the contingency between the IRT and reinforcement was varied. The reinforcement frequency under the DRL (IRT = 1.5 ± 0.5 sec) 4-sec and RI (IRT = 1.5 ± 0.5 sec) 7-sec schedules were essentially identical. In spite of equated reinforcement frequency on the two schedules, the DRL (IRT = 1.5 ± 0.5 sec) 4-sec schedule controlled both a lower rate of emission of the 1.0- to 2.0-sec IRTs and a different temporal pattern of emission. Evidence was also found in the present experiment to suggest that the temporal pattern of emitting a reinforced IRT class is similar to the pattern of responding on simple schedules of reinforcement.

EXPERIMENT II

The results of Experiment I suggested that different contingencies between the selected IRT class and reinforcement produce different temporal patterns of responding. Experiment II further explored this effect. The general strategy was to reinforce a 1.0- to 2.0-sec IRT on various schedules (fixed interval, fixed ratio, random ratio) and record cumulative emissions of the reinforced IRT over time.

METHOD

Subjects

Two adult male albino rats, obtained from the Holtzman Co., were maintained at 80% free-feeding body weight by food deprivation. Both subjects had histories of responding on schedules in which selected IRTs were reinforced.

Apparatus

The apparatus was identical to that used in Experiment I.

Procedure

Rat 69 responded on various random- and fixed-ratio schedules where 1.0- to 2.0-sec IRTs were reinforced. Rat 80 responded on fixed-interval schedules with respect to the same IRT. On all schedules, only lever presses terminating IRTs of between 1.0 and 2.0 sec were reinforced. On the random-ratio (RR) schedules, the 1.0- to 2.0-sec IRT was reinforced after a randomly varying number of emissions. The 1.0- to 2.0-sec IRT was reinforced after a

DRL (IRT = 1.5 ± 0.5 SEC) 4 SEC.

RI (IRT = 1.5 ± 0.5 SEC) 7 SEC

Fig. 3. Some representative cumulative records of emission of 1.0- to 2.0-sec IRTs on the DRL (IRT = 1.5 ± 0.5 sec) 4-sec and RI (IRT = 1.5 ± 0.5 sec) 7-sec schedules. The 1.0- to 2.0-sec IRTs are cumulated over time. Slash marks indicate reinforcement. Note that the maximum rate of emitting 1.0- to 2.0-sec IRTs is one per second.

fixed number of emissions on the fixed-ratio (FR) schedules. The first 1.0- to 2.0-sec IRT to be emitted after a fixed period of time was reinforced on the fixed-interval (FI) schedules.

RESULTS

Figure 4 shows sample cumulative records of performance on various schedules in which the 1.0- to 2.0-sec IRT was reinforced. In all records, emissions of the 1.0- to 2.0-sec IRT are cumulated over time. (Note that the maximum rate at which the 1.0- to 2.0-sec IRT can be emitted is one per second.) Records A, B, and C are from Rat 69; records D and E are from Rat 80. The different records show three consecutive sessions of performance on the following schedules: A—FR(IRT = 1.5 ± 0.5 sec) 10; B—FR(IRT = 1.5 ± 0.5 sec) 14; C—RR(IRT = 1.5 ± 0.5 sec) 10; D—FI(IRT = 1.5 ± 0.5 sec) 40 sec and E—FI(IRT = 1.5 ± 0.5 sec) 64 sec.

The cumulative records show that the different schedules controlled different patterns of emitting the 1.0- to 2.0-sec IRT. Performance on the FR schedules was characterized by a relatively constant rate of emitting the 1.0- to 2.0-sec IRT and occasional post-reinforcement pauses. The pauses after reinforcement were typically followed by a rapid transition to the terminal rate. Pauses after reinforcement were generally absent on the RR(IRT = 1.5 ± 0.5 sec) 10 schedule. Pauses after reinforcement were also observed on the FI schedules. Also,

"scallop" or positive acceleration within the intervals was sometimes observed on the FI schedules. The number of 1.0- to 2.0-sec IRTs emitted per interval on the FI schedules varied considerably.

DISCUSSION

The results of this experiment, as well as those of Experiment I, suggest that the temporal pattern of emitting a reinforced IRT class is dependent upon the contingency between the IRT class and reinforcement. These experiments suggest also that the pattern of emitting a reinforced IRT class is similar in many respects to the response patterns observed on conventional reinforcement schedules. The cumulative records of emission of the reinforced IRT class obtained in the present experiment resemble to a considerable degree those obtained by Ferster and Skinner (1957) for conventional reinforcement schedules.

GENERAL DISCUSSION

The results of the above experiments suggest that the behavior of a reinforced IRT class is similar in many ways to the behavior of simpler and more conventional operants such as lever pressing or key pecking. In particular, the present experiments suggest that both the rate and temporal distribution of a reinforced IRT class is dependent upon the contingency between the IRT class and reinforce-

Fig. 4. Sample cumulative records of emissions of 1.0- to 2.0-sec IRTs on: A—FR(IRT = 1.5 ± 0.5 sec) 10; B—FR(IRT = 1.5 ± 0.5 sec) 14; C—RR(IRT = 1.5 ± 0.5 sec) 10; D—FI(IRT = 1.5 ± 0.5 sec) 40 sec; and E—FI(IRT = 1.5 ± 0.5 sec) 64-sec schedules. Three consecutive sessions are shown for each schedule.

ment. The present experiments also suggest that emission of a reinforced IRT on different schedules of interresponse time reinforcement resembles quite closely performance on conventional reinforcement schedules.

While these findings support the basic assumption underlying attempts to account for schedule effects in terms of the differential reinforcement of IRTs, namely, that IRTs are operants, they also tend to complicate such analyses. The present data suggest that one must consider not only the frequency of reinforcement obtained by an IRT but also the contingency between the IRT and reinforcement when studying the effects of reinforcement on the emission of IRTs. Perhaps more importantly, the present findings raise the question of what concept can be evolved to explain the fact that IRTs themselves are subject to schedule effects. A concept such as the differential reinforcement of "times between successive emissions of a reinforced IRT" or "inter-IRT-time" is suggested by the present findings.

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