TWO-COMPONENT SCHEDULES OF DIFFERENTIAL-REINFORCEMENT-OF-LOW-RATE¹

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Two-component schedules of differential-reinforcement-of-low-rate were presented, where the contingencies specified separately two minimum interresponse times, t_1 and t_2 , required for reinforcement, depending on whether the interresponse time was initiated by, in one case, a reinforced response (t_1) or, in the other, a nonreinforced response (t_2). A distinctive pattern of responding developed on each of the two contingencies. Duration of an interresponse time approximated t_1 when the t_1 contingency was in effect, and t_2 when the t_2 contingency was in effect. This relationship persisted even when t_2 was shorter than t_1 , and responding at a higher rate on the t_1 contingency would have greatly increased the rate of reinforcement. Increasing the value of t_2 resulted in both longer interresponse times on the t_1 contingency, and a higher probability of a response-burst on those occasions when the contingency switched from t_1 to t_2 . The results indicated that both reinforced and nonreinforced responses functioned as discriminative events in determining the duration of following interresponse times.

On a differential-reinforcement-of-low-rate (DRL) schedule, a response is reinforced only if a specified minimum interval of time, t , has elapsed since the previous response. If a response occurs after a shorter interval it is not reinforced, and timing of a new interval starts from that response. One characteristic of DRL behavior is the development of sequences of responses spaced evenly in time, and separated by intervals just exceeding the minimum interresponse time (IRT) required for reinforcement. This characteristic makes the DRL schedule particularly suitable in studies concerned with the temporal control of behavior. (For reviews see Harzem, 1969; Kramer and Rilling, 1970).

However, the DRL schedule entails an important difficulty of analysis because two contingencies operate concurrently: (i) the reinforcement of responses that terminate criterion IRTs, and (ii) the resetting of the interval to zero as a consequence of responses

that terminate IRTs shorter than criterion. Changing the temporal criterion for the reinforcement of a response also changes the duration by which the availability of reinforcement is delayed after a nonreinforced response. For example, although the latter contingency has been said to be aversive (Caplan, 1970; Hearst, Koresko, and Poppen, 1964) there is no direct evidence to show this. Similarly, while reinforcement probably functions as a discriminative event in determining the duration of the next IRT (*e.g.*, Farmer and Schoenfeld, 1964; Weiss, Laties, Siegel, and Goldstein, 1966), this has not been shown directly because the temporal contingency is the same after reinforcement and after nonreinforced responses.

The present study designed a two-component DRL schedule in which t , the minimum IRT required for reinforcement, was specified separately for IRTs initiated by reinforced responses (t_1), and IRTs initiated by nonreinforced responses (t_2). In the experiments reported, t_1 was held constant, and the effects of several values of t_2 were investigated.

EXPERIMENT 1

METHOD

Subjects

Four naive male albino rats (103, 105, 106, and 107), 90 days old at the start of the ex-

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periment, were housed individually and maintained at 80% of their free-feeding weights. Water was freely available in the home cages.

Apparatus

The operant-conditioning chambers measured 18.5 cm high, 24 cm long, and 20 cm wide. The walls were sanded plate aluminum; on one of the 20-cm walls, a 5-cm wide lever protruded 1.5 cm into the chamber and could be operated by a force of approximately 10 g (0.1 N). A recess, 4 cm wide, 5 cm high, and 5 cm deep, was located in the center of the panel, 7 cm to the right of the lever. The reinforcer, 0.05 ml of a 30% solution of Nestlé's condensed milk in water, was delivered up to the floor of the recess by a motor-operated dipper mechanism. The dipper remained in the up position, and operated at each reinforcement, the dipping action taking approximately 0.8 sec. The chamber was housed in a sound-attenuating box, containing a 3-W light located on the ceiling and an exhaust fan, mounted on one side, producing an ambient noise at 60 ± 2 dB (reference level: 0.0002 dyn/cm at 1000 Hz). The scheduling and recording equipment were in a separate room.

Procedure

The basic schedule consisted of two separate contingencies: (i) if a reinforced response initiated an IRT, the response that terminated that IRT was reinforced only if it exceeded a specified minimum duration, t_1 (termed the t_1 contingency); (ii) if the response terminated an IRT shorter than t_1 , that response was not reinforced, and it initiated a different contingency that specified independently the minimum IRT, t_2 , required for reinforcement (termed the t_2 contingency). The t_2 contingency remained in effect until a response met the t_2 reinforcement criterion. At reinforcement, the contingency switched back to t_1 . In these terms, the conventional DRL schedule is the condition where t_1 and t_2 are equal.

Lever-pressing responses were trained in the first session. Starting in Session 2, the animals were placed on one of the pairs of schedule parameters (t_1 , t_2) in daily 1-hr sessions. In every case, t_1 was held constant at 20 sec and t_2 was changed after response stability had been attained with a given t_2 value.

The sequence of t_2 values, in seconds, was as follows: Animal 106: 20, 10, 60; Animal 107: 20, 30, 60; Animal 103: 30, 10; Animal 105: 30, 40. The number of sessions with each pair of parameters is shown in Table 1. Responding was considered stable when the response rate in any one session in a block of six successive sessions did not differ by more than 10% from the mean response rate for that block. Stability was reached, by this criterion, within the first 30 sessions. However, approximately 60 sessions were conducted with each t_2 value, since no previous information was available on schedules of this kind, and it was not known whether further changes would occur after initial stability. No such changes were observed.

RESULTS AND DISCUSSION

Figure 1 illustrates in detail the control of responding in the two components of the schedule. The data are from the final sessions with each t_2 value, and show sequences of IRTs on the last four occasions when the contingency switched from t_1 to t_2 , and back to t_1 .

In the top-left section, for example, an IRT is shown, exceeding t_1 and therefore being terminated by reinforcement. The next IRT was just short of t_1 ; consequently, the response terminating it was not reinforced, and the contingency switched to t_2 . The next IRT was short, followed by an IRT that met the t_2 criterion. The response terminating that IRT was reinforced and the criterion switched back to t_1 . A different example where response bursts followed responses that still failed to meet the t_2 criterion, is shown in the top row for Animal 107, on DRL 20-sec-60-sec. When the t_2 criterion of 60 sec was ultimately met, the following IRTs were just above 20 sec, meeting the t_1 criterion.

Table 1 shows the response and reinforcement rates, and the proportion of session time spent in the t_1 component, in the last two sessions of each condition. As the duration of t_2 increased, the response rates in both t_1 and t_2 components declined, although only slightly in the t_1 component. The rate of reinforcement in the t_2 component decreased also, whereas in the t_1 component it increased. The proportion of session time spent in the t_1 component showed some decline, this, and the decline in the rate of reinforcement in

Fig. 1. Sequences of individual IRTs, obtained on the last four occasions when the contingency switched from t_1 to t_2 and back to t_1 , on each condition, with each subject. Filled and open circles show reinforced and nonreinforced IRTs respectively, and dotted horizontal lines the durations of the minimum reinforced IRTs. The schedule parameters are given in seconds, at the top of each column. (t_1 = interresponse time initiated by a reinforced response, t_2 = interresponse time initiated by a nonreinforced response.)

Table 1

Number of sessions on each condition, the mean response and reinforcement rates, and the mean proportion of session time spent in the t_1 component. Data are from the last two sessions on each condition (t_1 = interresponse time initiated by a reinforced response; t_2 = interresponse time initiated by a nonreinforced response.)

Subject	Schedule Parameters ($t_1 = 20$ sec) t_2 (sec)	Number of Sessions	Response/Min			Reinforcements/Min			Time in t_1 (%)
			t_1	t_2	Overall	t_1	t_2	Overall	
106	10	65	2.89	4.82	3.43	1.76	2.90	2.07	73
	20	63	2.86	3.53	3.17	2.02	1.60	1.89	66
	60	65	2.84	2.48	2.68	2.25	0.62	1.45	51
107	20	65	3.03	4.73	3.96	1.80	1.14	1.43	45
	30	63	2.91	3.44	3.18	1.98	0.72	1.30	45
	60	67	2.80	2.44	2.55	2.24	0.34	0.93	32
103	10	63	3.07	6.20	4.33	1.17	2.91	1.88	60
	30	65	2.94	3.55	3.33	2.05	0.60	1.09	34
105	30	64	2.88	2.13	2.47	1.86	0.93	1.36	46
	40	65	2.85	2.09	2.50	2.15	0.82	1.52	53

the t_2 component, reflecting mainly the fact that t_2 was longer.

These relationships were reflected in the efficiency of performance, expressed as a percentage of responses that were reinforced. Figure 2 shows that in the t_2 component, efficiency declined with longer values of t_2 . However, in the t_1 component, efficiency was an increasing function of the duration of t_2 ; the longer the delay of reinforcement opportunity after a nonreinforced response, the greater was the proportion of reinforced responses in t_1 . Thus, it seems that the t_2 contingency affected responding in a way similar to adding a punishment contingency to DRL responses. For example, Holz, Azrin, and Ulrich (1963) administered a brief shock after every response on a DRL schedule, and found that with an ascending series of shock intensities response rate declined and reinforcement rate increased (see also Holz and Azrin, 1963).

Figure 3 shows the relative frequency distributions of IRTs for the t_1 and t_2 components, obtained in the last two sessions of each condition, with each subject. At all the schedule parameters used, responding was under the control of both t_1 and t_2 contingencies. As t_2 increased, t_1 distributions showed fewer IRTs shorter than t_1 , and the median IRTs in the t_1 component, successively shifted to longer durations. With greater values of t_2 , the t_2 distributions became flatter.

Fig. 2. Efficiency of performance, as a function of duration of t_2 . Overall efficiency (open circles) is shown, as well as efficiency in the t_1 (filled circles) and t_2 (filled squares) components. To calculate efficiency, the number of reinforcements in a component was divided by the number of responses emitted in that component, and the result was multiplied by 100 (cf. Table 1). Data are from the last two sessions on each condition.

There was a secondary mode in the region of 0 to 2 sec in all the t_2 distributions, but not in the t_1 distributions. Two or more responses

Fig. 3. Relative frequencies of IRTs on each condition shown separately for the t_1 and t_2 components in the left and right columns respectively. The numbers in brackets in the upper-left corner of each t_1 distribution give the duration, in seconds, of the median IRT of that distribution. Filled areas represent reinforced IRTs.

separated by such short IRTs, not exceeding 2 sec, are termed response bursts (Sidman, 1956). In some studies of DRL responding, bursts have not been observed (Kelleher, Fry, and Cook, 1959), but when observed, they have been found to be less frequent (Sidman, 1956) or absent (Kramer, 1968; Bradley, 1971) following reinforcement. In the present experiment also, no burst occurred after a reinforced response; that is, a reinforced response never initiated a burst. Figure 4 shows the probability of a burst (*i.e.*, the proportion of responses that initiated a burst) as a function of the duration of t_2 . The functions are shown separately for the responses that switched the contingency from t_1 to t_2 and for other nonreinforced responses. As t_2 increased, the probability of a burst also increased, but only for the responses involving

Fig. 4. The proportion of the responses that switched the contingency from t_1 to t_2 that were followed by bursts (crosses), and the proportion of other nonreinforced responses that were followed by bursts (filled circles), as a function of the duration of t_2 . These proportions are termed conditional probabilities. Data are from the last five sessions on each condition.

a switch from the t_1 to the t_2 contingency. There was no systematic effect on the bursts that occurred at other times in the t_2 component. Thus, the probability of a response burst on the occasions when the contingencies were switched, was an increasing function of how unfavorable was that switch.

One surprising aspect of the results was the persistence of the control of responding in the two components, even when t_2 was shorter than t_1 . With t_1 at 20 sec and t_2 at 10 sec, the frequency of reinforcement might have doubled had the subject made a response soon after each reinforcement, thus switching to the shorter t_2 contingency. Such a pattern of responding, which might be considered an optimal strategy on the DRL 20-sec-10-sec schedule, never developed in this experiment.

EXPERIMENT 2

This experiment explored the extent of the differential control in the two components of the schedule when t_2 was shorter than t_1 .

METHOD

Subjects

Four naive male albino rats (113, 118, 120, and 143), 90 days old at the start of the ex-

periment, were housed individually and maintained at 80% of their free-feeding weights, with constant access to water.

Apparatus

The apparatus was the same as in Experiment 1.

Procedure

Lever pressing was trained in the first session. Starting with Session 2, subjects were placed on one of the pairs of schedule parameters studied in this experiment, in daily 40-min sessions. Initially, two animals were placed on a DRL 20-sec-1-sec schedule, and two animals on DRL 20-sec-20-sec. For Subjects 118 and 120, t_2 was increased in small steps from 1 sec to 20 sec, and then it was returned, without the intervening steps, to 1 sec. For Animals 113 and 143, t_2 was decreased from 20 sec to 1 sec, and then returned to 20 sec, in small steps with Animal

113, and without the intervening steps with Animal 143.

Table 2 shows the order of conditions and number of sessions in each condition for each subject. Since in Experiment 1 performance was found to remain stable once the stability criterion was reached, in this experiment the t_2 value was changed soon after reaching the stability criterion.

RESULTS AND DISCUSSION

Table 2 shows the response and reinforcement rates and the proportion of session time spent on the t_1 component in the last two sessions of each condition. Despite the fact that all the t_2 values used were shorter than or equal to t_1 , the relations between the duration of t_2 and the response and reinforcement rates were the same as in Experiment 1. At t_2 increased, the response rate in the t_1 component decreased, with consistent increases in the rate of reinforcement in the t_1 compo-

Table 2

Number of sessions on each condition, the mean response and reinforcement rates, and the mean proportion of session time spent in the t_1 component. Data are from the last two sessions on each condition. (t_1 = interresponse time initiated by a reinforced response; t_2 = interresponse time initiated by a nonreinforced response.)

Subject	Schedule Parameters ($t_1 = 20$ sec) t_2 (sec)	Number of Sessions	Responses/Min			Reinforcement/Min			Time in t_1 (%)
			t_1	t_2	Overall	t_1	t_2	Overall	
113	20	45	2.97	6.97	4.20	2.20	1.41	1.97	66
	10	23	2.99	6.97	4.20	1.61	3.07	2.06	69
	5	21	3.00	10.94	4.42	1.53	6.79	2.47	82
	3	20	3.38	17.84	6.05	0.57	12.38	2.75	82
	1	21	4.91	40.23	10.32	0.16	26.29	4.16	85
	3	24	3.00	23.09	5.77	1.30	10.66	2.59	86
	5	22	2.97	15.91	5.62	1.63	5.26	2.37	80
	10	22	2.94	7.14	4.04	1.77	3.34	2.18	76
	20	23	2.88	4.29	3.50	2.04	1.06	1.61	56
	20	45	2.76	7.60	3.98	2.16	1.77	2.06	75
143	1	24	6.24	48.55	13.69	0.12	28.60	5.14	82
	20	25	2.78	7.03	4.06	2.30	1.27	2.02	73
	1	21	7.72	39.50	15.07	0.07	25.40	5.93	77
118	3	24	4.38	20.57	9.31	0.18	9.63	3.05	70
	5	24	3.11	15.04	6.31	1.17	5.29	2.27	73
	10	25	2.93	10.13	4.40	2.03	3.45	2.32	79
	20	24	2.84	7.55	4.57	2.09	1.29	1.80	63
	1	20	5.56	35.80	12.53	0.20	17.90	4.28	77
120	1	20	7.39	44.89	16.87	0.11	21.50	5.52	75
	3	23	4.52	20.64	9.18	0.21	10.61	3.22	71
	5	23	3.09	14.13	5.39	1.37	6.53	2.45	79
	10	24	2.87	7.62	4.13	1.92	2.60	2.10	73
	20	23	2.84	5.39	3.84	2.16	1.06	1.73	61
	1	21	5.63	48.47	13.14	0.09	26.10	4.65	82

nent. The proportion of session time spent in the t_1 component declined, as the value of t_2 increased.

The efficiency of performance was related to the value of t_2 . Figure 5 shows that with longer durations of t_2 , efficiency declined in the t_2 component and increased in the t_1 component. However, for Animals 113 and 120, the t_2 efficiency increased slightly when the duration of t_2 was increased from 1 to 3 sec. The order of presentation of t_2 values had little effect on these relationships, and similar data points were obtained when the values were introduced a second time.

Figure 6 shows for each subject the relative frequency distributions of IRTs on both schedule components, in all conditions. The modes of the t_2 distributions decreased and increased in marked steps as the duration of t_2 was decreased from 20 sec to 1 sec, and increased back to 20 sec. The value of t_2 also affected the t_1 distributions where, as t_2 decreased, the proportion of nonreinforced IRTs increased and the mode of the distribution

shifted to shorter IRTs; when the duration of t_2 was increased, the direction of these changes was reversed. As in Experiment 1, response bursts occurred in the t_2 component but not in the t_1 component.

Animals 118 and 120 were first trained on a DRL 20-sec-1-sec schedule, and had no experience with a schedule requiring a low response rate. Despite this, the IRTs obtained from these subjects in the t_1 component were relatively long. There was some evidence of a residual effect of exposure to prior parameter values. When the t_2 value of 1 sec was re-instated after exposure to other t_2 values, the median IRT in the t_1 component was longer than it was at first exposure to the t_2 value of 1 sec. This residual effect resembles the phenomenon of "metastability" observed by Staddon (1965) in conventional DRL schedules.

The distinct control over the temporal distribution of responses in the two components of the schedule persisted even when the duration of t_2 was shorter than t_1 . With all the t_2 values used, except when t_2 was equal to t_1 , the optimal behavior would have been the emission of a (nonreinforced) response shortly after each reinforcement, thus re-instating the more favorable t_2 contingency. This would be a two-link chain where reinforcement signalled a very short IRT and a nonreinforced response signalled an IRT meeting the t_2 criterion. Such a pattern, however, never developed.

GENERAL DISCUSSION

In the present study, distinct control of responding by two temporal contingencies was established in the absence of added cues. Differential responding on two different DRL schedules has been previously observed in multiple and concurrent schedules (Shimp, 1968; Zimmerman and Schuster, 1962). A different schedule in which temporal relationships operate in a way similar to the schedule studied here is free-operant avoidance, where the response rate is controlled by two unsignalled temporal parameters (Sidman, 1953; 1966). The present results extend this finding because in free-operant avoidance, only one of the parameters, the R-S interval, specifies the consequence of a response, whereas in the schedule studied here, two such contingencies were in operation.

Fig. 5. Efficiency of performance, as a function of duration of t_2 . Overall efficiency (open circles), and efficiency in the t_1 component (filled circles) and t_2 component (filled squares) are shown. Unconnected symbols are redetermination points. To calculate efficiency, the number of reinforcements in a component was divided by the number of responses emitted in that component, and the result was multiplied by 100 (cf. Table 2). Data are from the last two sessions on each condition.

Fig. 6. Relative frequencies of IRTs on each condition, shown separately for the t_1 and t_2 components in the left and right columns respectively. The numbers in brackets in the upper-left corner of each t_1 distribution give the duration, in seconds, of the median IRT of that distribution. Filled areas represent reinforced IRTs.

The sequential patterns of the individual IRTs on the occasions when the two contingencies switched strongly indicate the presence of discriminative control. Sequential effects have been previously noted in conventional DRL schedules, showing that reinforced responses occur more often after reinforcement than after nonreinforced responses (Carter and Bruno, 1968a, b; Ferraro, Schoenfeld, and Snapper, 1965; Weiss *et al.*, 1966). The present study provides further evidence for this discriminative function of reinforcement and shows that a nonreinforced response can also exert discriminative control over the next response, effectively signalling intervals as long as 60 sec (*cf.* Figure 1).

Response bursts have been observed mainly in two kinds of situations: free-operant avoidance, and DRL schedules. In both situations, it has been difficult to identify the origin and maintenance of these bursts (*cf.* Sidman, 1966). Blough (1966), for example, concluded that response bursts have a "special character" not sensitive to stimulus variations. The present results identify in DRL schedules a source of control of bursts: the less favorable the consequence of a nonreinforced response, the higher the probability that this response will initiate a burst.

An important aspect of the present data was the continuing occurrence of relatively long pauses after reinforcement, even when

t_2 was shorter than t_1 . Under these conditions the emission of a (nonreinforced) response, soon after reinforcement, would re-instate the more favorable t_2 contingency, resulting in a higher rate of reinforcement. One explanation of the fact that such a pattern did not develop is suggested by the finding that in those schedules where the contingency is initiated by the subject's response, long pauses occur between reinforcement and the initiating response. This phenomenon has been observed with two-manipulandum DRL schedules (Mechner and Guevrekian, 1962) and with response-initiated fixed-interval schedules (Chung and Neuringer, 1967; Lowe, Davey, and Harzem, 1974; Shull, 1970). The occurrence of long postreinforcement pauses in response-initiated schedules, even when this results in considerable reduction in the rate of reinforcement, presents a challenge to established conceptions of reinforcement. It appears that in schedules where the response terminating the postreinforcement pause (*i.e.*, the response initiating the schedule) is never reinforced, the reinforcing stimulus signals a period of nonreinforcement, that is, the occasion for not responding (*cf.* Lowe *et al.*, 1974). This effect is observed not only in the response-initiated schedules, but also in conventional schedules, for example, the fixed-ratio schedule. As Gott and Weiss (1972) pointed out with reference to such schedules: "what is puzzling is the fact that long post-reinforcement times lower the density of reinforcement. Given everything else known about the actions of reinforcement, such a finding is anomalous . . ." (p. 495). This anomaly is apparently consistent across many schedules, and remains to be more fully investigated.

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