THE EFFECT OF MULTIPLE S^Δ PERIODS ON RESPONDING ON A FIXED-INTERVAL SCHEDULE: V. EFFECT OF PERIODS OF COMPLETE DARKNESS AND OF OCCASIONAL OMISSIONS OF FOOD PRESENTATIONS[1]

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In pigeons under fixed-interval schedules of reinforcement, responding during most of the interval can be suppressed by stimulus conditions never present when a response is promptly followed by reinforcing stimuli. When the external stimuli obtaining immediately before reinforcement are presented during brief probe periods in the course of the interval, the rate of responding in the probe depends on the temporal position of the probe during the interval; the rate of responding is lower during a probe early in the interval than during one late in the interval. The present experiments show that the temporal dependency still holds (1) in birds with no experience under unmodified fixed-interval schedules, (2) when the time between probes is spent in complete darkness, and (3) when food presentations are omitted at the end of 50% of intervals. The results strengthen and extend the conclusion from previous studies that the time relations themselves are the primary control of rate of responding under fixed-interval schedules of reinforcement.

Under fixed-interval schedules of reinforcement (FI), rate of responding characteristically increases through each interval (Ferster and Skinner, 1957, Chapter 5). Even when responding is suppressed for most of the interval, the rate during short probes increases as the probe occurs later in the interval, and, indeed, the mean rate in the probe can correspond to the mean rate for that segment in unsuppressed intervals (Dews, 1966).

The experiments on probes involved a modified FI schedule. The schedule was an FI in that after a fixed interval of 500 sec from the onset of a continued stimulus (a keylight) a response was followed promptly by food. The modification of the FI was the presence of an additional stimulus (a houselight) throughout the interval except during the final 50-sec segment and one other, earlier, 50-sec segment. A response when the houselight was present was thus never followed promptly by the reinforcer (food), so the houselight was an S^Δ. Responding was suppressed when S^Δ was present. Responses were sometimes reinforced (according to the FI schedule) when the keylight alone was present, so the keylight without houselight was an S^D. The main findings were that the rate of responding in the earlier 50-

sec S^D probe depended on when during the interval that probe occurred, and that the actual rate of responding during the probe was similar to what it would have been during the corresponding segment of an uninterrupted FI. These findings led to the inference that responding under an FI schedule is more under temporal control than under control of continuous chained mediating behavior.

Two features of the previous experiments with single short probes during the interval merit further examination. First, the three pigeons studied had had extensive experience under FI 500 sec, and the experiments with single, early S^D probes were interspersed as single sessions during otherwise continued daily exposure to an FI schedule with alternating 50-sec S^D and S^Δ periods. The question arises whether the dependence of the rate in the S^D probe on when it occurs in the interval requires extensive and concurrent FI training. Second, the schedule involved continuous presentation of the keylight during the 500 sec fixed-interval. Although responding was effectively suppressed[2] during the interval by the additional presence of the houselight except during the probes, the regular 500-sec

[2]"Suppressed" in the sense that responding which would have occurred during a segment of the FI was prevented by the presence of the S^Δ. The S^Δ, like the pre-aversive stimulus preceding an adventitious shock in traditional "conditioned suppression" procedures (Ferster and Skinner, 1957), thus abrogates responding.

period of keylight presentation made the schedule, in respect to the keylight stimulus, a conventional FI 500-sec schedule. The question arises of whether complete darkness except during probes would give similar results. Accordingly, Exp I was conducted on birds that had never been exposed to a conventional FI schedule and were not so exposed during the experiment. Further, the keylight was present only during the brief probes; for the rest of the interval the bird was in complete darkness. The results show that the dependence of rate of responding during the S^D probe on when the probe occurs in the interval does not require exposure to a conventional FI schedule or the continuous presence of the keylight through the interval.

In Exp I and in similar previous studies, each interval concluded with the presentation of food. It is possible that the increasing tendency to respond during a probe as the time to the next food presentation draws closer depends on control of responding by a direct consequence of time since last eating. Experiment II examines this suggestion. If time since last eating is the predominant determinant of rate of responding in the probe periods, then omitting food at the end of an interval should have profound effects on rate of responding in the probes of the next interval. A schedule of food presentation was therefore introduced, under which 50% of the intervals concluded with food presentation and 50% concluded without it. In none of the three birds studied were the rates of responding in the probe recognizably different according

ing to whether the previous interval did, or did not, conclude with food.

EXPERIMENT I

The subjects were two male White Carneaux pigeons, weighing on free feeding about 600 and 525 g respectively. During the experiments their weights were maintained near 420 and 400 respectively. The apparatus, response mechanism, and food reinforcer were standard and the stimuli were as in the previous experiments (Dews, 1962).

Schedules

Stimuli were presented in two routines (Fig. 1). The sequence under the Early Probe Schedule was as follows: at the beginning of the session or following the reinforcing stimuli, the houselight was present for 50 sec. There was then complete darkness for 100 sec, followed by a white keylight which terminated at the end of 50 sec, independently of responding. There was complete darkness for 300 sec. A white keylight was again presented for 50 sec and then continued until the next response occurred, whereupon food was presented and the sequence of stimuli started again. If no response were made within 50 sec of availability of the reinforcer, the sequence of stimuli terminated with presentation of houselight of the beginning of the next sequence. The Late Probe Schedule was identical in all respects except that the first keylight period started 300 sec after the end of the houselight period, continued 50 sec, and was followed by the start of the second keylight period 100 sec later. Under both schedules, the time between cessation of the houselight and availability of the reinforcer at a response was 500 sec.

Procedure

Before serving in the present experiments, both birds were trained briefly under a delayed reinforcement procedure. After a period of free feeding, they were reduced again in body weight. Then Bird 223 was subjected to seven sessions under the Early Probe Schedule, 32 sessions under the Late Probe Schedule, 32 sessions under the Early Probe Schedule, and then, finally, eight sessions under the Late Probe Schedule. Concurrently, Bird 236 was subjected to 32 sessions under the Early Probe
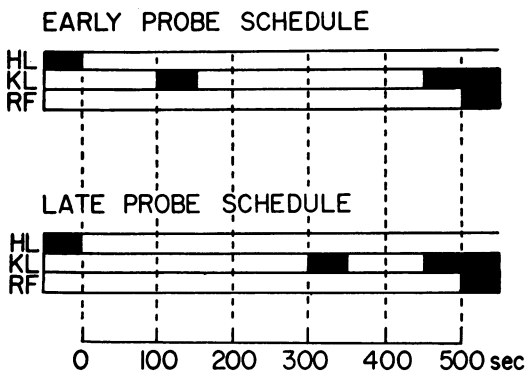

Fig. 1. Diagram of schedules. The shaded portions show when the stimulus or condition obtained. HL—houselight. KL—keylight. RF—following first response in this period food is presented and stimulus-sequence starts again from left.

Schedule, 34 sessions under the Late Probe Schedule and a final seven sessions under the Early Probe Schedule. The standard session was 30 stimulus-sequences and sessions were conducted five days per week. The last 10 sessions of the 32- or 34-session series, which were preceded by a session under the same schedule on the previous day, were utilized for tabulation and statistical purposes.

Results

Responding was confined to S^D periods (Fig. 2). Responding in the 50-sec S^D periods was not uniform. The most common pattern was of a pause at the beginning of the S^D period followed by responding at an increasing rate, giving the cumulative record an upward concavity (Fig. 2) that has been called a miniature FI pattern (Dews, 1962).
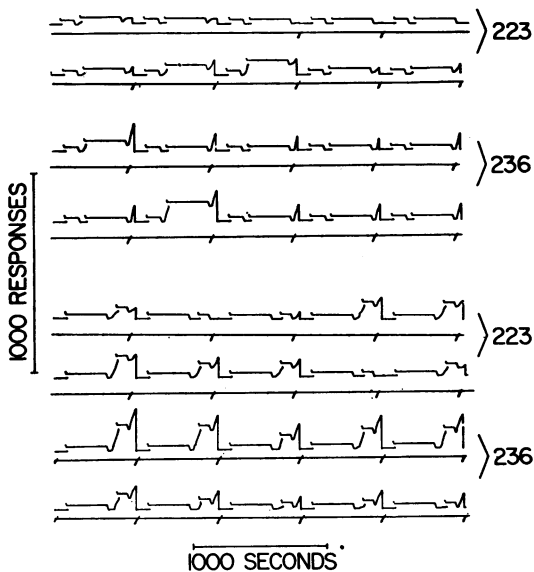

Fig. 2. Cumulative records of responding on the corresponding parts of two sessions for each of the two birds of Exp I under each of the two schedules. For each session, the upper curve shows cumulative responding; the pen resets to the baseline at the end of each stimulus-sequence, and the line is downset both during the houselight period (immediately after reset) and during the two keylight periods of the sequence. The lower event marker shows presentations of the reinforcer. The upper four sessions show the birds under the Early Probe Schedule, the lower four sessions under the Late Probe Schedule.

Note that responding is confined to periods when the keylight (S^D) is present. The rate of responding in the initial S^D period of each cycle is higher under the Late Probe Schedule than under the Early Probe Schedule.

The mean rate of responding in the first S^D period of each interval under the Early Probe Schedule was less on the average than the rate in the first S^D period under the Late Probe Schedule (Table 1). In spite of high variability from session to session, there was no overlap in the mean rates of responding in the first S^D periods under the Early Probe and Late Probe Schedules for either bird in any of the steady-state sessions shown in Table 1. The position of the probe did not appreciably affect responding in the terminal S^D period. The rate of responding of Bird 236 in the first S^D period of the Late Probe Schedule was only slightly, though fairly consistently, lower than the rate in the terminal S^D period. For Bird 223, the average rate in the first S^D periods of the Late Probe Schedule was actually higher than the average rate in the terminal S^D periods in six out of 10 of the sessions shown in Table 1.

The rate of responding in the first S^D periods by Bird 223 under the Late Probe Schedule never fell below 0.6 of the rate in the terminal S^D period. When the schedule was changed to Early Probe, the rate in the first S^D period fell to below 0.6 of the rate in the terminal S^D period, and remained consistently below 0.6 in every session until the schedule was changed back to the Late Probe Schedule, whereupon the relative rate promptly became greater than 0.6 (Fig. 3). Bird 236 showed similar changes in relative rates. On the Early Probe Schedule, the rate in the first S^D period fell over the course of the first four sessions until it was less than 0.6 of that in the terminal S^D period. It then remained below 0.6 in every session until the schedule was changed to Late Probe, whereupon, after three sessions of transition the relative rate rose above 0.6 and remained so, consistently, in every session until the final schedule change (Fig. 3). Thus, the effect of the position of the probe, early or late, on rate of responding in the probe was reversible.

More evidence for the strong control of the precise temporal relations of the schedule is provided by the exaggerated reaction of Bird 223 to the final change from the Early Probe to the Late Probe Schedule. Postponing the time of the probe 200 sec in the FI 500 sec caused a transition phase in which, for as long as two sessions, the rate of responding in the first S^D period was increased more than 10-fold. The experiment was discontinued before steady-state had been reestablished.

EXPERIMENT II

Under the Early Probe Schedule, the first S^D period occurred (except in the first sequence of a session) 150 sec after the birds had eaten food from the magazine. Under the Late Probe Schedule the first S^D period was 350 sec after food. The terminal S^D periods of both sched-
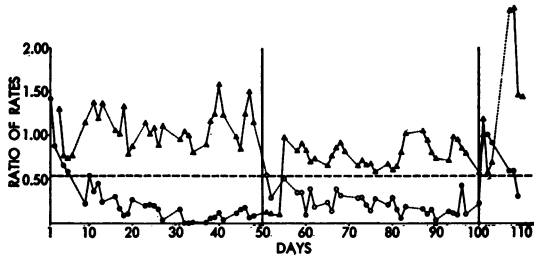

Fig. 3. Responding in the first S^D periods of each cycle of a session as a fraction of the responding in the second and terminal S^D periods of the session as related to a) the time of occurrence of the first S^D period and b) the chronological sequence of sessions.

° Bird 223 under the Early Probe Schedule
▲ Bird 223 under the Late Probe Schedule
• Bird 236 under the Early Probe Schedule
▲ Bird 236 under the Late Probe Schedule

Solid lines connect consecutive daily sessions. Dotted lines connect sessions between which one or more days intervened. Vertical lines show when the schedule was changed. The horizontal dotted line separates the points for the relative rates in the first S^D periods under the two schedules; when steady-state had been approached, the Early Probe Schedule gave points consistently under the line while the Late Probe Schedule gave points consistently above the line.

ules started 500 sec after food. It was shown in Exp I that the rate of responding in the S^D periods was lowest in the Early Probes, higher in the Late Probes, and on the average, highest in the terminal S^D periods of both schedules. The mean rate of responding was thus a monotonically increasing function of time since food. In order to see whether some direct consequence of time since eating was controlling the rate of responding, food presentation was omitted at the end of some sequences of stimuli. Following a food omission, then, an Early Probe started 700 sec after food; on the hypothesis of control by time since food, the rate should be higher than in the terminal S^D periods in sequences following food.

The experiment was conducted on three male White Carneaux pigeons, 23, 125, and 132, with experience under a variety of schedules including a multiple FI 180 sec FI 360 sec FI 540 sec FI 600 sec. The apparatus was similar to that of Exp I.

Schedules

The schedule was the Early Probe Schedule of Exp I except that the food presentation was omitted at the end of some stimulus-sequences (see below).

Procedure

The birds were subjected to about 15 sessions each of 10 to 15 stimulus-sequences of the Early Probe Schedule. Then in three con-

Table 1
Rates of Responding (in Responses per Second) in S^D Periods

Consecutive session under schedule	Early Probe Schedule				Late Probe Schedule			
	First S^D period		Terminal S^D period		First S^D period		Terminal S^D period	
	Bird		Bird		Bird		Bird	
	223	236	223	236	223	326	223	326
21	0.013	0.009	0.195	1.185	0.258	1.049	0.258	1.703
22	0.074	0.011	0.376	1.400	0.138	1.991	0.171	1.511
24	0.041	0.017	0.358	1.348	0.303	1.378	0.259	1.689
25	0.049	0.093	0.303	1.503	0.403	1.761	0.321	1.713
26	0.014	0.091	0.352	1.304	0.299	1.005	0.189	1.059
27	0.039	0.163	0.321	1.404	0.432	1.066	0.347	1.309
29	0.013	0.056	0.134	1.435	0.317	1.071	0.373	1.440
30	0.102	0.225	0.237	1.413	0.332	1.504	0.265	1.515
31	0.018	0.237	0.158	1.343	0.134	1.515	0.089	1.572
32	0.097	0.089	0.426	1.311	0.134	1.373	0.173	1.597
Mean	0.046	0.099	0.286	1.365	0.275	1.271	0.245	1.511
Standard error	0.011	0.027	0.032	0.028	0.034	0.085	0.028	0.064

Sessions 23 and 28 were omitted from this table because they were conducted on Mondays when the birds had not been subjected to experimental sessions for two days (see Procedure).

secutive sessions, scheduled food presentations were irregularly omitted (see Fig. 4), such schedule cycles being concluded by a response which produced the houselight. The 36-member sequence of food (F) and no food (N) cycles was as follows: F, F, F, N, N, F, N, F, N, F, F, N, N, N, F, N, F, N, F, F, F, N, N, F, F, N, N, N, F, F, N, F, N, F, N, N, [F, F, F, N, N, . . . and so on]. Each session started randomly in the sequence.

Results

Even the relatively short exposure to the schedule was sufficient for miniature FI scallops to develop in some S^D periods (Fig. 4). In each bird, the mean rate of responding in the first S^D period was less than that in the terminal S^D period (Table 2), in conformity with the findings of Exp I.

Table 2 shows that the rate in the first S^D periods following no food-intervals was lower than the rate in terminal S^D periods following food-intervals. Indeed, the rates in the first S^D periods of FI following no food were not recognizably different from the rates in the first S^D periods of FI following food presentation (Fig. 4 and Table 2). Therefore the difference in rates in the first and terminal S^D periods must be due to characteristics of the schedule and not to direct dependency on time since eating.

DISCUSSION

The present experiments confirm that the rate of responding in a short S^D probe period depends on the temporal position of the probe period within the schedule cycle. Prior or concurrent exposure to conventional FI schedules is not necessary for manifestation of the dependency, nor is continuous presence of the keylight, or, indeed, any light through the FI.
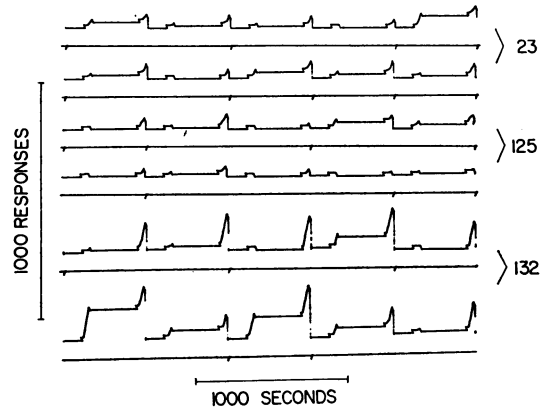

Fig. 4. Cumulative records of responding in parts of two of the three final sessions in Exp II. The conventions are the same as in Fig. 2 except that in this figure the cumulative record pen was downset at all times except when the keylight was present. Hatch marks at the end of a schedule cycle on the lower horizontal record show food presentation. Performance in the probe periods is unaffected by whether or not food had been presented at the conclusion of the preceding sequence of stimuli.

Passage of time in complete darkness can control responding in the pigeon in a qualitatively similar manner to passage of time in the presence of visual stimuli; the difference between the rates of responding in the initial S^D periods of the Early and Late Probe Schedules of Exp I was controlled entirely by whether the preceding time in darkness was 100 sec or 300 sec. The bird usually cannot be heard moving in the chamber during complete darkness. There are no grounds for postulating mediating behavior.

In the preceding paper of this series (Dews, 1966) a gradient of increasing rate of responding in an S^D probe was found as the probe came closer to time of food presentation. Under the Late Probe Schedule of Exp I, evidence of such a gradient was seen in only one (236) of the two birds; the second bird (223) responded

Table 2

Rates of Responding (in Responses per Second) in S^D Periods.

	Following stimulus-sequence concluding with food		Following stimulus-sequence concluding without food presentation	
Pigeon	First S^D period	Terminal S^D period	First S^D period	Terminal S^D period
23	0.500	0.584	0.332	0.538
125	0.194	0.436	0.158	0.234
132	0.628	2.064	0.706	2.280
Mean	0.440	1.028	0.398	1.050

as much or more in the first S^D period as in the terminal S^D period. The difference in rates in the first and terminal S^D periods for 223 was small (Table 1) and far from being statistically significant; it may therefore be no more than a chance finding. It is possible, however, that the tendency for a fall in rate between the first and terminal S^D periods by Bird 223 was the result of a real factor in the control of FI responding that was made manifest by the modifications of the FI schedule. The present results do not provide a basis for further speculation.

The inappreciable effect of omitting food at the conclusion of 50% of FI in Exp II is an example of the great strength of control acquired by schedule and discriminative stimuli as opposed to the immediate effects of the reinforcing stimuli. The pigeons were getting about 0.1 to 0.3 g of food at each food presentation in the present experiments. Larger amounts of food might be expected to have longer direct effects in controlling responding, but it is interesting to note that in the experiments of Ferster and Hammer (1965) administration of a full day's food supply over a short period of time to primates on a 18 to 24 hr delay of reinforcement schedule seemed to have a more important effect in maintaining responding than in controlling its temporal pattern.

The concept of schedules of reinforcement arose from studies of intermittent as opposed to continuous reinforcement. The intermittency is according to a schedule, and the schedule has been considered a convenient way of arranging stimuli and behavior at the time a response is reinforced. According to the view of a schedule as a means of attenuating reinforcement by making it intermittent responding under FI consists of a lot of unreinforced responses concluded by one reinforced response. Unreinforced responding is maintained because the stimulus conditions during the FI are identical with those obtaining when the reinforced response occurs and the animal has only an imperfect "clock", based on its own pattern of responding (Ferster and Skinner, 1957, p. 266).

The results presented in this series of papers urge a different view of FI responding, and, by extrapolation, of responding under other schedules of reinforcement. Under an FI schedule, the distinction between a reinforced response and an unreinforced response is on the basis of the controlling hardware. When a timing device has completed a phase of its operation, the reinforced response can precipitate the reinforcing stimuli; preceding unreinforced responses cannot cause the presentation of the reinforcing stimuli. From the point of view of the subject, however, the distinction is not clear. The reinforced response is followed promptly by the reinforcing stimuli; the preceding unreinforced responses are also followed by the reinforcing stimuli, though not quite so promptly. Indeed, the whole pattern of FI responding is followed by the reinforcing stimuli and so, in a sense, is reinforced. Schedules of reinforcement are therefore to be regarded as convenient ways of reinforcing whole patterns of responding. Such a view of schedule control accounts naturally for second order schedules (Kelleher, 1966).

The present results further emphasize the importance of the schedule of reinforcement in organizing patterns of behavior over long periods of time. The effect of the schedule survives prolonged suppression of responding by S^Δ of complete darkness and even irregularity in presentation of the food reinforcer. It appears that the schedule of consequences of responses and of presentation of stimuli can achieve a high degree of autonomy in the control of responding; autonomy, that is, from the nature of the consequences of the responses and the nature of the stimuli. It is the pattern of the contingencies and stimuli presentations, that is, the schedule itself that determines the pattern of responding.

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