FACTORS INFLUENCING RESPONDING UNDER MULTIPLE SCHEDULES OF CONDITIONED AND UNCONDITIONED REINFORCEMENT

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Two experiments examined pigeons' responses under multiple schedules of conditioned and unconditioned reinforcement. In one component, responses produced food according to a fixed-interval schedule; in a second component, responses produced brief stimuli according to a fixed-ratio schedule. When brief-stimulus presentations were paired with food in the first component, rates in the second component were usually higher than 10 responses per minute. When pairing in the first component was eliminated, responding continued to be maintained in the second component. Elimination of food presentation from the first component substantially decreased responding in the second component, even though the brief stimulus had not been paired with food. Experiment II demonstrated that response rate was affected by the duration of both the second component and the brief stimulus. The results suggest that three conditions are important in maintaining responding with brief-stimulus presentations: (1) pairing the brief stimulus, at least initially, with food, (2) maintaining unconditioned reinforcement in one component, and (3) employing optimal brief-stimulus and component durations.

Key words: conditioned reinforcement, unconditioned reinforcement, multiple schedules, brief-stimulus schedule, component duration, brief-stimulus duration, key peck, pigeons

The concept of conditioned reinforcement has provided a theoretical framework for explaining long and orderly sequences of behavior in the absence of unconditioned reinforcement (*e.g.*, Hull, 1943). While several techniques have been used to study conditioned reinforcement, attention has recently focused on brief-stimulus second-order schedules. Under a second-order schedule, behavior generated by a schedule is treated as a unitary response and reinforced according to another schedule (*e.g.*, Kelleher, 1966). For example, food might be presented after completion of five fixed-interval (FI) schedules. A brief stimulus (*e.g.*, 2-sec houselight) presented at completion of each component schedule has been shown to result in patterns of responding within components similar to those generated by food; for example, with FI components, be-

havior is characterized by a pause after each brief stimulus followed by positively accelerated responding (Stubbs, 1971). The similarity between patterns maintained by brief-stimuli and food has resulted in conceptualizing the brief stimulus as a conditioned reinforcer (*e.g.*, Marr, 1969).

However, certain aspects of second-order schedules make a conditioned-reinforcement analysis difficult. Stubbs (1971) argued that under certain second-order schedules, the brief stimulus acquires discriminative properties that might mask conditioned-reinforcement properties. For example, with FI components there is a fixed temporal relationship between the presentation of the brief stimulus and food. The stimulus might acquire discriminative properties by signalling that food is unavailable until at least the next interval has elapsed. This fixed temporal relationship could be partly responsible for the pause after each stimulus and the pattern that follows.

Schedules that avoid a fixed temporal relationship between the brief stimulus and unconditioned reinforcement are perhaps better suited to study conditioned reinforcement (*e.g.*, Clark and Sherman, 1970; Zimmerman, 1963, 1969). One procedure (Thomas, 1969) involved multiple schedules of conditioned and uncon-

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ditioned reinforcement. Pecking produced food in one component, while responding in a second component produced only a brief stimulus that accompanied food presentations in the first component. Responding was maintained in the second component even though it never produced food. Since responding occurred in the absence of food, a conditioned-reinforcement analysis was not confounded by a fixed temporal relationship between the brief stimulus and food.

An important theoretical aspect of conditioned reinforcement is whether or not a stimulus must be paired with food to establish a conditioned reinforcer (Hull, 1943). While many studies involving second-order schedules have compared paired and nonpaired brief stimuli (*e.g.*, Marr, 1969; Stubbs, 1971; Stubbs and Cohen, 1972), there have been only a few comparisons of the two types of stimuli in multiple schedules (Thomas, 1969; Thomas and Johanson, 1970). Accordingly, the present study was designed to analyze responding under multiple schedules of food and brief stimuli that would seem to reduce temporal stimulus control, and concentrated on the role of pairing the stimulus with food.

EXPERIMENT I

METHOD

Subjects

Two White Carneaux (2 and 12) and three Silver King (4, 5, and 13), experimentally naive, male pigeons were maintained at 75% free-feeding weights.

Apparatus

The left key (R. Gerbrands Co.) of a two-key chamber was used. A minimum force of 0.06 N operated the response key, which was transilluminated by red, green, or white light. A houselight was located above and slightly to the right of the key. Grain was presented by a Lehigh Valley Electronics pigeon feeder. White noise, provided through a speaker in the chamber, masked extraneous sounds. Standard electromechanical relay and timing circuitry controlled sessions.

Procedure

Part 1. Pecking was maintained under an FI 40-sec schedule; the first response on the red key after 40 sec produced 4-sec access to

grain. The food magazine was illuminated red during the 4 sec. Sessions, conducted six days a week, ended after 100 food presentations. Pigeons 2 and 4 had 36 and Pigeon 5 had 37 sessions. For the first 11 sessions, the response key was darkened during each food presentation. In the remaining sessions, during each food cycle the red keylight turned white, the houselight was illuminated, and the white noise was interrupted.

In all following conditions, responding was maintained under multiple schedules of reinforcement. Under the basic schedule, responses in the red component produced food under an FI 40-sec schedule. Following the fourth food cycle, the key turned green for 60 sec. Here, responses produced a brief stimulus according to a fixed-ratio (FR) 11 schedule; every eleventh response changed the key from green to white, illuminated the houselight, and interrupted the white noise for 4 sec. Then, the key turned red again. Sessions ended after 15 red and green cycles. Partially completed fixed ratios reset when components alternated. If a brief-stimulus presentation was in progress when the 60-sec component timed out, the 4-sec cycle continued before components switched.

Table 1 summarizes the sequence of conditions. A major aim was to determine whether maintained pairing of the stimulus with food was essential in establishing a conditioned reinforcer. This analysis involved pairing the brief stimulus with food in Conditions 1, 3, 4, and 10 (*i.e.*, the stimulus accompanied each food cycle in the red component) and not pair-

Table 1
Sequence of Conditions for Parts 1 and 2

<i>Birds #2, #4, #5</i> <i>Conditions</i>		<i>Birds #12, #13</i> <i>Conditions</i>
1	Paired	Nonpaired
2	Nonpaired	Paired
3	Paired	Nonpaired
* 4	Paired-No Stimulus	Paired
5	Nonpaired	Nonpaired
6	Nonpaired-Noise On	Nonpaired-Timeout
7	Nonpaired	Nonpaired
8	Extinction	
9	Nonpaired	
10	Paired	
11	Nonpaired	
12	Nonpaired-DRO 40-sec	
13	Nonpaired-Timeout	
14	Nonpaired	

*Bird #2 was not exposed to Condition 4.

ing it in Conditions 2, 5, 6, 7, 9, 11, 12, 13, and 14 (*i.e.*, during food cycles the key was darkened and the white noise remained on).

Several control conditions examined factors responsible for responding in the green component. (1) The brief stimulus was omitted (Condition 4). Although the stimulus was paired with food in the red component, responses had no scheduled consequences in the green component. This condition was conducted to see if responding had to be attributed to the brief stimulus. (2) The brief stimulus was altered by eliminating white-noise interruption (Condition 6). Every eleventh response turned on the white-key light and houselight but the white noise remained on. This condition examined whether responding was maintained by the termination of an aversive noise. (3) To determine the role of unconditioned reinforcement, food was eliminated (Condition 8). Responding in the red component had no scheduled consequences and the key turned green after 40 sec. Responding in the green component continued to produce the brief stimulus. (4) Food was presented under a differential-reinforcement-of-other behavior (DRO) 40-sec schedule (Condition 12). Food was presented every 40 sec if no response was emitted in the red component, and every response reset the 40-sec interval. Components switched after four food cycles. This condition examined whether responding in the red component influenced responding in the green component. (5) A 3-min timeout was imposed after the green component (not after the red component). After each green component, the chamber was darkened for 3 min and responses had no scheduled effects (Condition 13). This condition determined if responding was adventitiously reinforced by the onset of the red key. Conditions 13 and 14 were conducted between Conditions 8 and 9 of Experiment II; therefore, several conditions intervened between Conditions 12 and 13. Conditions were changed when no increasing or decreasing trend in response rate was observed in the green component for at least five consecutive sessions.

Part 2. Part 1 was partially replicated. However, the stimulus was not paired with food during the first condition for Pigeons 12 and 13 to see if a nonpaired stimulus could control behavior without a history of food association.

Pecking was maintained under an FI 40-sec schedule of reinforcement for 30 sessions, each lasting 80 reinforcements. The key was darkened and the white noise remained on during each 4-sec food cycle. Responding was then maintained for seven conditions under the multiple schedules used in Part 1. During Condition 1, the brief stimulus was nonpaired. It was paired in the second condition, then nonpaired, paired, nonpaired, nonpaired with a 3-min timeout, and finally nonpaired.

RESULTS

Part 1. Comparisons of paired and nonpaired brief-stimulus conditions are summarized in Figure 1, which shows daily response rates in the green component for Conditions 1, 2, 3, 5, 10, and 11. In the first paired condition, responding was established and maintained, although at different levels. When pairing was removed in Condition 2, responding persisted and, in fact, increased for Subject 5. Redetermination of the paired condition revealed no differences between nonpaired (Condition 2) and paired (Condition 3) brief-stimulus presentations for Subjects 4 and 5, while pairing increased rates for Subject 2. In the remaining conditions of Figure 1, both paired and nonpaired stimuli maintained responding, and no consistent differences were observed between the two types of stimuli.

Figure 2 shows daily response rates in the green component for the control conditions. (1) When the brief stimulus was omitted in the green component, responding decreased to zero or near-zero levels. (2) Responding was maintained when the white noise remained on during brief-stimulus presentations. (3) When food was omitted (extinction) response rates decreased, ceasing for Subject 2 but persisting at a low variable rate for over 30 sessions for Subjects 4 and 5. Following extinction, responding increased when food was again presented. (4) Eliminating responding in the red component with a DRO schedule had no effect on responding in the green component. (5) No change in responding was observed when a 3-min timeout was imposed between components.

Representative cumulative records from the last session of Conditions 9 to 12 (nonpaired, paired, and DRO schedules for Subject 4) are presented in Figure 3. Responding characteristic of fixed-interval schedules occurred in the

Fig. 1. Daily response rates in the green component for Conditions 1, 2, 3, 5, 10, and 11. S^P (open circles) represents paired brief-stimulus presentations, and S^N (filled circles) represents nonpaired presentations.

red component. Responding was also maintained in the green component with as few as one FR schedule and as many as five schedules completed. Patterns of responding in green were characteristic of patterns seen under FR schedules of food presentations, *i.e.*, pausing followed by a high steady response rate. Negligible responding occurred during the 4-sec brief stimulus. The record from the DRO schedule shows that responding in the red component was eliminated, while responding in the green component continued.

Median response rates in the red component for the last five sessions of each condition ranged from 10 to 38 responses per minute for

Subject 2, from 11 to 139 responses per minute for Subject 4, and from 15 to 34 responses per minute for Subject 5. In some sessions, response rate in the green component was higher than response rate in the red. Responding under the FI schedule appeared unrelated to responding under the FR. Increases and decreases in responding in the red component, either within or between conditions, were not systematically accompanied by similar increases and decreases in the green component.

Part 2. Daily response rates in the green component for the seven experimental conditions (Subjects 12 and 13) are presented in Figure 4. Minimal responding occurred in the

Fig. 2. Daily response rates in the green component for Conditions 4, 6, 7, 8, 9, 12, 13, and 14. "No Stim" refers to Condition 4, where the stimulus was removed from the green component. Pigeon 2 was not exposed to this condition. Under the Noise-On condition (Condition 6), the white noise was not interrupted during the 4-sec brief stimulus. EXT refers to food extinction, DRO to differential-reinforcement-of-other behavior, and TO to timeout. All brief stimuli were nonpaired, except Condition 4 where open circles represent paired brief-stimulus presentations. Conditions not labelled represent baselines where food reinforced responding in the red component according to an FI schedule and nonpaired brief stimuli reinforced responding in the green component according to an FR 11 schedule.

first condition. Responding increased when the stimulus was paired with food, and decreased again when the pairing was removed. Re-instating pairing yielded a second increase in responding; therefore, paired-nonpaired differences were observed during the first four conditions. However, in the remaining conditions, responding was maintained by the non-paired stimulus. As in Part I, the 3-min timeout did not affect responding; also, comparable response rates, patterns, and variability were observed here.

Response rates in the red component were variable, ranging from 25 (median for the last

five sessions) to 89 responses per minute for Subject 12 and from 30 to 82 responses per minute for Subject 13.

EXPERIMENT II: MANIPULATION OF COMPONENT AND BRIEF-STIMULUS DURATION

In Experiment I, response rates in the green components were usually greater than 10 or 20 responses per minute. Other brief-stimulus procedures of this type have generated much lower response rates. Thomas and Johanson (1970), for example, reported rates of approxi-

Fig. 3. Cumulative records of Subject 4 from the last session of Conditions 9 to 12. The top record shows non-paired stimuli (S^N), the second record shows paired stimuli (S^P), the third record shows nonpaired stimuli again, and the bottom record shows responding under the differential-reinforcement-of-other behavior (DRO) schedule. Each response stepped the pen once; it was reset to the baseline after each component. The event pen was up during food components and down during brief-stimulus components. Downward deflections of the response pen show brief-stimulus presentations.

Fig. 4. Daily response rates in the green component for the seven conditions of Part 2 for Subjects 12 and 13. S^N (filled circles) represents conditions where the brief-stimulus was not paired with food, S^P (open circles) represents conditions where it was paired, and TO represents conditions where a 3-min timeout was introduced after the green component.

mately two to three responses per minute, and Zimmerman (1969) obtained rates of about four to six responses per minute. In the present procedure, the brief-stimulus duration was 4 sec, while in other studies it was typically 0.3 to 1 sec (Thomas, 1969; Thomas and Johanson, 1970; Zimmerman, 1969). Additionally, a 1-min component duration was employed here, compared to 3.5 or 4 min used by Thomas (1969) and Thomas and Johanson (1970). Since differences in component and brief-stimulus duration might be responsible for differences in rates, these variables were systematically manipulated in Experiment II.

METHOD

Subjects and Apparatus

The subjects and apparatus were the same as those used in Part 1 of Experiment I.

Procedure

Table 2 summarizes the sequence of conditions and the number of sessions under each. Subjects were exposed to the multiple schedules described in Experiment I. With the brief-

stimulus duration constant at 4 sec, the component duration was varied from 1 to 4 min, according to the order outlined in Table 2. With the component duration constant at 1 min, the brief-stimulus duration was varied from 0.5 to 4 sec. Nonpaired brief stimuli were used in all conditions except Condition 8. In this condition (0.5-sec brief stimulus), the stimulus was paired in a slightly different way: the brief stimulus accompanied food for only the first 0.5 sec of the food cycle; the key was then darkened, the white noise came on, and the houselight was extinguished for the remaining 3.5 sec of the food cycle. Therefore, the 0.5-sec brief stimulus was paired with food for 0.5 sec; in Experiment I, the 4-sec stimulus was paired with food for 4 sec.

RESULTS

Response rate in the green component varied as a function of brief-stimulus and component duration. Figure 5 shows that response rate in the green component varied directly in relation to brief-stimulus duration. Both paired and nonpaired 0.5-sec brief-stimulus

Table 2
Sequence of conditions in order of occurrence. The brief stimulus was paired in Condition 8 (S^p) but non-paired in other conditions.

Condition	Component Duration (min)	Brief-Stimulus Duration (sec)	Birds		
			Sessions		
			#2	#4	#5
1	1	4	10	13	17
2	2	4	34*	15	12
3	4	4	27	17	12
4	1	4	8	7	12
5	1	0.5	16	6	6
6	1	2	8	15	10
7	1	4	22	9	7
8 - S ^p	1	0.5	7	6	7
9**	4	4	8	7	6
10	1	4	10	7	8

*The brief stimulus was accidentally paired during the sixth session for Subject 2.

**Conditions 13 and 14 of Experiment I intervened between Conditions 8 and 9.

Fig. 5. Response rate as a function of brief-stimulus duration. Data are medians and ranges of the last five sessions of Conditions 4, 5, 6, 7, and 8. The component duration was 1 min across conditions. The number above the ranges represents the sequence of conditions.

presentations generated the lowest response rates. Higher rates were maintained for Subjects 4 and 5 with 2- and 4-sec brief-stimulus presentations; for Subject 2, the low rate persisted at the 2-sec duration but increased at 4 sec. No consistent differences were observed between paired and nonpaired brief-stimulus presentations.

Figure 6 shows overall response rates as a function of component duration. Response rates in the first 1-min component determination were similar to those of Experiment I. Increasing the component duration to 2 min produced equivocal results. Rates increased for

Fig. 6. Response rate as a function of green-component duration. Data are medians and ranges of the last five sessions of Conditions 1, 2, 3, 4, 9, and 10. The brief stimulus was 4 sec across conditions. The number above the ranges represents the sequence of conditions. Data from Condition 4 are also found in Figure 5 and are presented here for comparative purposes.

Subject 2, decreased for Subject 4, and remained approximately constant for Subject 5. Although there was variability between the three determinations of the 1-min component, and considerable overlap in the ranges, the lowest median response rates were produced by the 4-min component.

Cumulative records showed that responses were emitted at a high constant rate until the ratio was completed. Reduced overall response rate was thus a function of increased postreinforcement pause.

DISCUSSION

This study demonstrated that responding may be maintained indefinitely by scheduling brief stimuli according to FR schedules. Responding in the green component occurred at relatively high rates, with considerable session-to-session variability. Three conditions seemed important in controlling responding: (1) the brief stimulus had to be paired, at least initially, with food, (2) intermittent food presentations were required, and (3) relatively long brief-stimulus presentations and short component durations appeared optimal.

This study supports previous reports (Birnbauer, 1971; Thomas, 1969; Thomas and Johanson, 1970) showing that responding may be maintained under multiple schedules of conditioned and unconditioned reinforcement. These studies have shown that the effect is not limited to the FR schedules of brief-stimulus presentations and FI and DRO schedules of food presentations used here.

Several conditions showed that the brief stimulus controlled responding in the green component. First, responding was not negatively reinforced by white-noise termination. Keeping the white noise on during the brief stimulus had no effect on performance. Second, responding was not adventitiously reinforced by appearance of the red component: (1) patterns of responding characteristic of FR schedules were established, and no responding was observed during the brief stimulus; (2) removing the brief stimulus from the green component eliminated responding; and (3) imposing a 3-min timeout between components had no effect.

Both paired and nonpaired brief-stimulus presentations maintained responding. These findings are contrary to previous data showing

that nonpaired brief stimuli exert little or no control over responding (*e.g.*, Clark and Sherman, 1970; de Lorge, 1967; Marr, 1969; Thomas, 1969). It appears that under these conditions, a stimulus must be paired with food initially to establish a conditioned reinforcer. With sufficient pairings, however, the stimulus may reinforce responding without continued association with the unconditioned reinforcer.

The persistent effect of pairing a brief stimulus with food has been reported elsewhere. Marr and Zeiler (1974) reported partially irreversible effects in conjoint schedules of conditioned and unconditioned reinforcement. Some authors (de Lorge, 1967; Kelleher, 1966) have suggested that control by nonpaired stimuli in second-order schedules may stem from the prior history of food association.

Several studies involving second-order schedules have shown that nonpaired brief stimuli may control responding even without a history of food pairing (*e.g.*, Stubbs, 1971; Stubbs and Cohen, 1972). Similar findings have been reported under percentage-reinforcement schedules (*e.g.*, Ferster and Skinner, 1957). These schedules differ from multiple schedules in a very important respect: in second-order schedules, responding produces both food and brief stimuli, and there is a fixed temporal relationship between these two events. It has been argued (*e.g.*, Stubbs, 1971) that this fixed temporal relationship is an important factor in establishing control by nonpaired stimuli in second-order schedules (*i.e.*, the stimulus acquires discriminative properties). In the present multiple schedules, however, there was no consistent temporal relationship between the brief stimulus and food. Rather, responding occurred in the presence of a stimulus that explicitly signalled the absence of food (*i.e.*, food was presented in the red component but never in the green). Thus, the nonpaired stimulus seemed to have a reinforcing function without possible discriminative functions.

While the temporal relationship between brief-stimulus and food presentations differs in multiple and second-order schedules, both schedules require the continued presence of food for responding to be maintained. Responding in the green component declined substantially with extinction in effect for 40 sec in the red component. The decline was also found in an unreported condition when the

red component was 160 sec. Similar findings have previously been reported (e.g., Thomas, 1969; Zimmerman, 1969). In those experiments, responding ceased when food was removed, although some subjects (like Subjects 4 and 5 of this study) continued to respond at low variable rates for many sessions. Previous reports have explained the decline by arguing that discontinuation of the pairing of the brief stimulus and unconditioned reinforcement was responsible. In the present study, however, responding declined even though a nonpaired stimulus had reinforced responding. The conditioned-reinforcement effect may require the maintenance of responding in the experimental situation with unconditioned reinforcement. Data from the DRO condition do not support this suggestion, however, since responding in the green component persisted while responding in the red component was eliminated.

Experiment II demonstrated that decreasing brief-stimulus duration and increasing component duration tended to reduce overall response rates. A 1-min component in combination with a 4-sec brief stimulus provided the optimal conditions for generating responding in these experiments. The particular values chosen in previous (e.g., Thomas and Johanson, 1970) experiments (i.e., 3.5-min component and 0.7-sec brief stimulus) could be partly responsible for the lower rates reported, although other differences may also be responsible (e.g., type and schedule of brief-stimulus presentation).

Studies that have examined stimulus duration with other brief-stimulus procedures have shown additional roles of stimulus duration. Cohen, Hughes, and Stubbs (1973), for example, varied the duration of a brief stimulus presented in a second-order schedule. Increasing the duration from 0.5 to 8 sec yielded more pronounced patterning within the FI components. This increase was attributed to the greater saliency of the longer stimulus presentations. Similar results have been reported by Staddon and Innis (1969). Decreasing brief-stimulus duration did not, however, seem to affect how responses were distributed in time under the FR schedule. The main effect was to generate fewer FR units.

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