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TEMPORAL CONTROL ON INTERVAL SCHEDULES: WHAT DETERMINES THE POSTREINFORCEMENT PAUSE?

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On fixed-interval or response-initiated delay schedules of reinforcement, the average pause following food presentation is proportional to the interfood interval. Moreover, when a number of intervals of different durations occur in a programmed cyclic series, postreinforcement pauses track the changes in interval value. What controls the duration of postreinforcement pauses under these conditions? Staddon, Wynne, and Higa (1991), in their linear waiting model, propose control by the preceding interfood interval. Another possibility is that delay to reinforcement, signaled by a key peck and/or stimulus change, determines the subsequent pause. The experiments reported here examined the role of these two possible time markers by studying the performance of pigeons under a chained cyclic fixed-interval procedure. The data support the linear waiting model, but suggest that more than the immediately preceding interfood interval plays a role in temporal control.

Key words: postreinforcement pause, fixed-interval schedules, cyclic schedules, temporal control, pigeons

The ability to predict the occurrence of important events, such as the availability of food, has obvious survival value. In their natural habitats, many species behave in ways that indicate that they are capable of making such predictions. When important events occur at regular intervals or at fixed times following a signal, prediction must involve some sort of timing process. A number of theories have been suggested to account for timing behavior (e.g., Gibbon, 1977; Killeen & Fetterman, 1988; Staddon & Higa, 1991; Staddon, Wynne, & Higa, 1991). The experiments reported here examine temporal control of responding by pigeons on time-based schedules of food presentation.

A fixed-interval (FI) schedule provides the simplest time-based rule according to which responses can produce reinforcers (Ferster & Skinner, 1957). One consistent feature of the FI response pattern is the postreinforcement pause (PRP), a cessation of operant responding during the early portion of the fixed interval. On simple FI schedules, after extended training, the average pause stabilizes at a constant proportion (about one half to two thirds) of the interfood interval (IFI) (Schneider, 1969). Although the typical "scalloped" pattern of responding that characterizes performance on FI schedules has been studied for years, there is still little agreement on the mechanism(s) controlling this behavior.

The idea that some aspect of the IFI is important in determining the onset of key pecking on FI schedules was studied by Shull (1970), using a procedure that required pigeons to make at least one operant response to initiate the FI; that is, the interval was timed, not from the preceding food presentation, but from the first response. In order to obtain food most efficiently on such response-initiated FI schedules, a key peck should be made immediately following food presentation. Pigeons seem unable to do this; a PRP inevitably occurs on these schedules that extends the IFI (Shull, 1970, 1971; see also Innis & Honig, 1979). Shull (1970) suggested that either total IFI or the work period (time since the first peck in the interval) controlled PRP duration. Later, Shull (1971) concluded that PRPs on FI and response-initiated FI schedules are determined by the work period in preceding IFIs. He also found no difference in performance when an exteroceptive stimulus was associated with the work period and when it was not.

Using a procedure closely related to Shull's, Wynne and Staddon (1988) examined the behavior of pigeons on what they labeled response-initiated-delay (RID) schedules. A RID schedule is similar to a response-initiated FI

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schedule; however, in the RID procedure, the first response after food presentation changes the color of the response key and initiates a predetermined delay to the next food presentation. No further responding is required to produce food. Under these conditions, birds also did not respond optimally—a pause, proportional to the IFI and labeled waiting time in this procedure, occurred before the delay was initiated. Staddon et al. (1991) presented a dynamic model for interval-schedule timing called one-back linear waiting. They proposed that waiting time on RID schedules is automatically determined by the preceding IFI. Moreover, linear waiting involves an obligatory (automatic) process that the animal cannot override even if it means reducing the rate of food presentation.

When IFIs of more than one duration are programmed during an experimental session, temporal control—defined by a PRP appropriate to the interval value—may or may not develop. If interfood time is unpredictable and some very short IFIs are programmed (random-interval schedules or appropriately constructed variable-interval schedules), no PRPs occur and operant responding continues at a constant rate throughout the session. However, on a number of schedules in which a series of intervals is presented in a regularly repeated order, control of pausing by IFI duration has been reported; that is, changes in PRPs "track" the changing IFIs. Harzem (1969) found that rats, trained on schedules in which IFIs increased in an arithmetic progression across the session (progressive-interval schedules), paused progressively longer as interval durations increased. Innis (1970, 1981; Innis & Staddon, 1971) showed that the PRPs of pigeons increased and decreased on schedules in which IFIs increased and decreased repeatedly across a session (cyclic-interval schedules), the pauses tracking the changes in interval duration. Higa, Wynne, and Staddon (1991), using a cyclic variant of the RID procedure, reported that pigeons' waiting times tracked a sinusoidally changing series of IFIs.

Although PRPs changed across changing intervals in the schedules described above, pauses during intervals of a particular duration were typically shorter than PRPs during intervals of the same duration presented on a simple FI schedule (Innis, 1981). As intervals became longer, this discrepancy increased. Innis and Staddon (1971) obtained a power function relationship, with an exponent of about 0.82, between PRPs and IFI on a number of cyclic schedules in which intervals changed according to an arithmetic progression.

The experiments reported here were directed at determining the factors that control the postreinforcement pause on cyclic-interval schedules. Experiment 1 looked at the relative roles of total IFI and a signaled delay to reinforcement in controlling the PRP on chained cyclic-interval schedules. Experiment 2 examined these variables on a chained (cyclic) schedule that programmed a constant IFI.

EXPERIMENT 1

Staddon et al. (1991) proposed one-back linear waiting to account for the PRP on a number of RID schedules they had studied. They hypothesized that waiting time is obligatory, proportional to IFI duration, and controlled by the most recent time marker. The most salient time marker preceding food is the previous food presentation, and they suggested that it (thus, the total IFI) controls the pause. However, in the RID procedure there are two salient time markers in the preceding interval—food presentation and the onset of the stimulus that initiates the delay to food. Food presentation as a time marker implicates the entire duration of the IFI in the control of the PRP. Stimulus change (and/or the response that produces it) as a time marker involves only the delay to food presentation. In Experiment 1, we were concerned with identifying which of these time markers controls the postreinforcement pause.

Cyclic-interval (CI) schedules were used to permit the examination of pauses during a number of different intervals within a single session. These schedules also allowed us to investigate temporal tracking. Although the timing data discussed above imply that tracking results from temporal control by immediately preceding IFIs, results of studies involving exposure of animals to other patterned inputs suggest that they can learn to anticipate the events in a series. For example, Hulse and his associates (e.g., Hulse & Dorsky, 1979) found that rats can learn a pattern of reinforcer presentations and act in anticipation of expected amounts of reward. It is possible that pigeons can learn the series of IFIs on a cyclic schedule. If this were the case, we might find evidence of anticipation in the PRPs observed.

In order to evaluate the relative control of PRPs by total IFI and by a stimulus signaling food, pigeons were studied using two-component chained schedules of reinforcement. Figure 1 gives a schematic representation of a single IFI of such a schedule. Following food presentation, the response key is red and the timer controlling the duration of this initial component, labeled $I(1)$ in the figure, starts. A peck after $I(1)$ has timed out changes the keylight to green and starts the timer controlling the duration of the second component, $I(2)$. Thus the programmed IFI is $I(1) + I(2)$. Because a response was required to terminate both components, the component durations actually experienced by subjects were determined by the time to respond at the end of each component, shown as $t(1)$ and $t(2)$; the experienced IFI then is $t(1) + t(2)$. For the schedules studied here, the programmed duration of one component was constant (fixed), whereas the other changed cyclically across the session according to an arithmetic progression. Two such schedules were used. On one, the constant component was $I(1)$ and the cyclic component was $I(2)$; for the other schedule, the order of presentation was reversed.

One cycle of each schedule is represented in Figure 2. Overall, each schedule provides the same series of cyclically changing IFIs (constant plus cyclic components). If food presentation is the relevant time marker (i.e., if IFI duration controls the PRP), then time to the first response should be similar on both schedules. However, if pauses are controlled by the signaled delay to food (indicated by the onset of the stimulus associated with the second component), the pattern of pauses should differ on the two schedules. All pauses should be of about the same duration when the second component is constant, but they should track the changing component durations when it is cyclic. A third, although less salient, time marker is the first peck in the IFI, and thus the work time that it initiates. On the RID schedules, only a single peck was required and it produced the stimulus change. In the present study, if the bird's first peck occurred before the first component had timed out, then the work period and the second component (delay stimulus) duration were not identical.

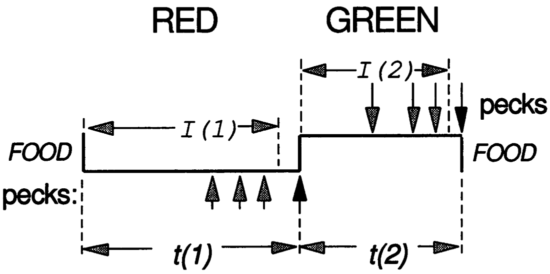


Fig. 1. Representation of a single interfood interval on the chained schedule used in this study. $I(1)$ is the programmed duration of the first (red) component, and $I(2)$ is the programmed duration of the second (green) component of intervals on the schedule. The component times actually experienced are indicated by $t(1)$ and $t(2)$. Pecks are indicated by the arrows, with closed arrows differentiating effective key pecks. See text for further details.

METHOD

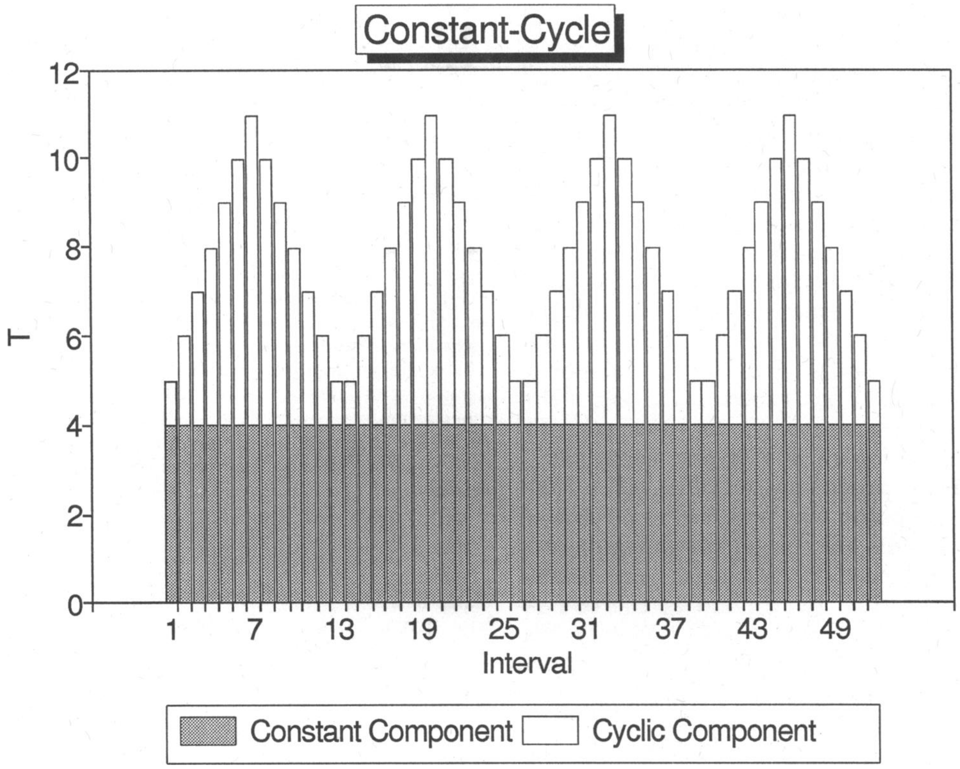
Subjects

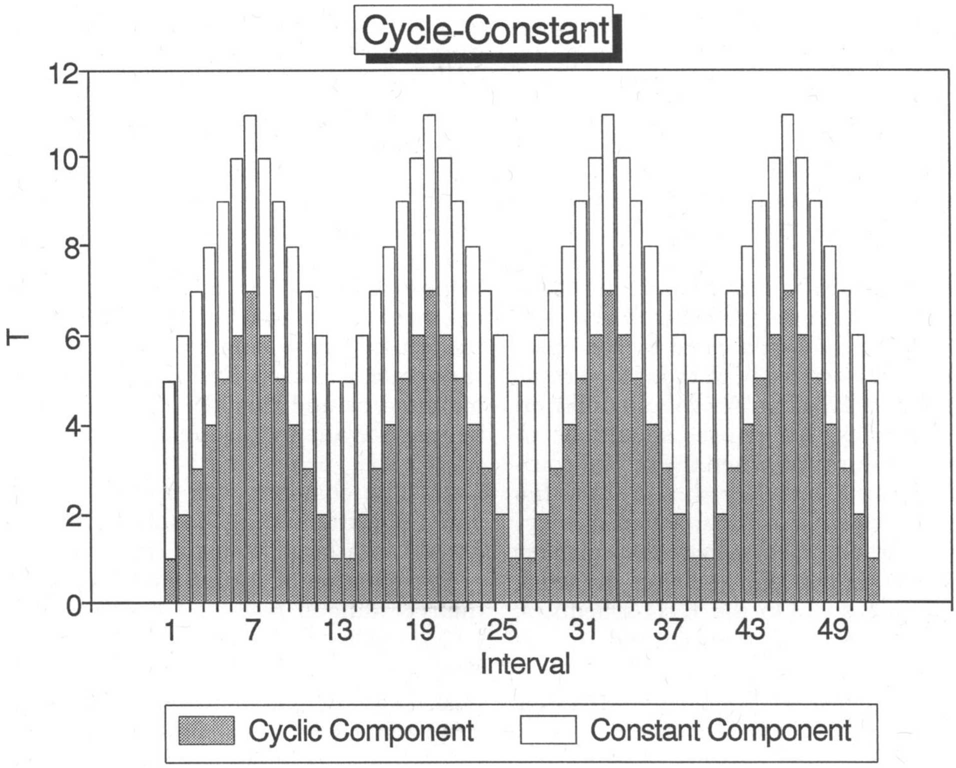
Subjects were 4 White Carneau pigeons with previous experimental experience, although not with CI schedules. The birds were maintained at approximately 80% ad lib weights by limiting access to food; they received free access to water in their home cages. The birds were housed in individual cages in a room with a 12:12 hr light/dark cycle.

Apparatus

A standard operant conditioning chamber (36 cm by 34 cm by 31 cm) was used. Two response keys (2.5 cm in diameter) were mounted 17 cm apart on the front panel; only the left key, requiring 0.15 N (15 g) of force to operate, was used. Red and green bulbs were mounted behind this key. Mixed grain could be made available through an opening in the front panel, below and between the response keys. The chamber was housed in a sound- and light-attenuating box that in turn was housed in a large acoustic chamber.

Presentation of stimuli and reinforcers and the recording of responses were controlled by a Commodore® 64 computer housed in an adjoining room. Data were recorded to disk and later transferred to a Zenith® XT-compatible computer for data analysis.


Constant-Cycle
T
0
2
4
6
8
10
12
1
7
13
19
25
31
37
43
49
Interval
Constant Component
Cyclic Component


Cycle-Constant
T
0
2
4
6
8
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12
1
7
13
19
25
31
37
43
49
Interval
Cyclic Component
Constant Component

Table 1

Order of conditions for each bird in Experiment 1 and the number of sessions (in parentheses) in each condition.

Subject	Order			
	1	2	3	4
Bird 41	cycle-constant $T = 5$ (57)	cycle-constant $T = 2$ (25)	constant-cycle $T = 2$ (25)	constant-cycle $T = 5$ (22)
Bird 43	cycle-constant $T = 2$ (49)	cycle-constant $T = 5$ (23)	constant-cycle $T = 5$ (27)	constant-cycle $T = 2$ (22)
Bird 46	constant-cycle $T = 5$ (49)	constant-cycle $T = 2$ (24)	cycle-constant $T = 2$ (30)	cycle-constant $T = 5$ (20)
Bird 49	constant-cycle $T = 2$ (35)	constant-cycle $T = 5$ (24)	cycle-constant $T = 5$ (27)	cycle-constant $T = 2$ (22)

Procedure

Each daily session involved presentation of four repetitions of a series of 13 IFIs. Each interval in the series consisted of two components (Figure 1). The programmed duration (I) of one of these was constant (an FI component), while the duration of the other changed cyclically across successive intervals according to an ascending, followed by a descending, arithmetic progression (CI component). The intervals in each cycle increased in T-s steps from T s to $7T$ s and back to T s. The programmed duration of the constant component was always $4T$ s. The order of the two components in the interfood interval and two T values, 2 and 5 s, yield the four conditions of the experiment: constant-cycle $T = 2$ and constant-cycle $T = 5$, a cycle of which is represented in the top panel of Figure 2; and cycle-constant $T = 2$ and cycle-constant $T = 5$, shown at the bottom of Figure 2.

During the first component of an interval the response key was red, and a peck was required after the component timed out (indicated by the closed arrow in Figure 1) to move to the second component, during which the key was green (keylight colors were reversed for 2 of the birds). A peck at the end of the second component (closed arrow, Figure 1) turned off the keylights and houselights and produced 3-s access to mixed grain. In operant conditioning terminology, this is a two-component chained schedule of reinforcement. Each bird eventually received each of the four conditions in a counterbalanced order. Table 1 shows the order of conditions for each bird in Experiment 1 and the number of sessions in each condition. Conditions were not changed until a bird had received at least 20 sessions in the condition.

RESULTS AND DISCUSSION

The time of each peck in all interfood intervals was recorded. From this was extracted the time until the first peck in the first component of each interval, the PRP, shown in Figure 1 as $t(0)$; the time of the first peck in the second component of each interval, the latency; the time until the last peck in the first component, that is, the duration of the first component, $t(1)$; and the time of the last peck of the second component, the duration of the second component, $t(2)$. The experienced durations of the components were summed to produce an accurate measure of the IFIs actually received by each bird: $t(1) + t(2)$. The data of interest here are the PRPs. The response latencies, in general, were very short, indicating that once the birds began pecking they continued to respond steadily until food was presented.

←

Fig. 2. Schematic representation of a single cycle of the schedules used in Experiment 1, indicating the durations of the first and second components of interfood intervals (IFIs). Top panel: constant-cycle schedule; bottom panel: cycle-constant schedule.

Postreinforcement Pauses Across Cycles

Figures 3 through 6 show the relationship between the IFIs, both programmed and experienced, and the PRPs in each condition. In order to reduce the daily and individual variability, median data for each condition were used, with medians calculated for each individual interval across the last 15 sessions and all subjects in each condition. Because responses were required to terminate each component of an interval, interfood times could vary substantially if long delays occurred in either component; thus, both the programmed IFIs and the average IFIs experienced by the subjects are shown. Data from only the last three of the four cycles of a session are presented, because "warm-up" effects were often observed during the first few intervals of a session.

The top panel of Figure 3 shows mean median PRPs for the last three cycles of the session for the constant-cycle $T = 5$ condition. The lower panel presents a transformation of these data so that times ranged from 0 to 1. Data were normalized by subtracting the minimum value of each data set from each point and dividing by the range (maximum value − minimum value). This type of transformation controls for individual variability and permits easy inspection of the phase relationship between the input (IFI) and output (PRP) patterns. Similarly, Figure 4 shows data for the constant-cycle $T = 2$ condition and the corresponding normalized pattern. The data from the cycle-constant $T = 5$ and $T = 2$ conditions are shown in Figures 5 and 6, respectively.

The pattern of pauses exhibited by the birds shows clearly that temporal tracking did occur. The PRPs (shown by asterisks) follow the pattern of the programmed (open squares) and experienced (closed squares) IFIs. The simplest method of ascertaining tracking is to compare where the longest and shortest PRPs occur in relation to the input IFIs. If the PRP (output) and schedule (input) cycles are aligned (i.e., with the shortest pause occurring in the shortest interval, etc.), the two cycles are said to be in phase. A phase lag of 1 for the PRP cycle indicates that durations of PRPs correspond to the values of the just-preceding (one-back) IFIs. A phase lag of 2 means that PRPs correspond to the interval two back, and so forth. For the constant-cycle $T = 5$ condition (Figure 3, bottom), the shortest PRP in each cycle falls in the interval immediately following the shortest IFI, and in the constant-cycle $T = 2$ condition (Figure 4, bottom), the pattern is similar. However, the longest PRPs sometimes occur two intervals after the maximum IFI (a phase lag of 2). Performance was similar in the cycle-constant conditions; the $T = 5$ condition (Figure 5) shows tracking with a lag of between one and two intervals, whereas the $T = 2$ condition (Figure 6) clearly shows tracking with a lag of two intervals, particularly for the long intervals.

In general, as a comparison of the PRP data in Figures 3 through 6 shows, tracking was better during the constant-cycle conditions. Quality of tracking was defined in terms of the amplitude of the PRP cycle; cycle amplitude—the difference between the longest and shortest pause in a cycle—was greater during the constant-cycle conditions. However, because a chained schedule was in effect, if birds were not pecking when a component timed out, the IFI duration was extended. The actual IFI pattern experienced in the constant-cycle conditions was more consistent with respect to the programmed intervals than it was in the cycle-constant conditions. The relationship between the programmed and experienced IFIs can be seen in the upper panels of Figures 3 through 6. The amplitude of the experienced IFI cycle was reduced in the cycle-constant conditions, because the PRPs often exceeded the programmed duration of the first component during the shorter IFIs, reducing the range of actual interval durations received. This was most apparent on the cycle-constant $T = 5$ schedule. If the PRP is determined by the experienced IFI, then tracking might be expected to be better in the constant-cycle conditions because the IFI cycle has a greater amplitude.

Pause data for individual subjects during each condition of the experiment are shown in Figure 7 for the constant-cycle schedules and Figure 8 for the cycle-constant conditions. Although there were differences in the degree of cycling displayed by individual birds, the performance of the individuals on the two types of schedules, at each value of T, is well represented by the average.

Relationship of Pauses to IFIs

Another way to identify temporal control on cyclic schedules is to look at the correlation between PRPs and IFI durations at various

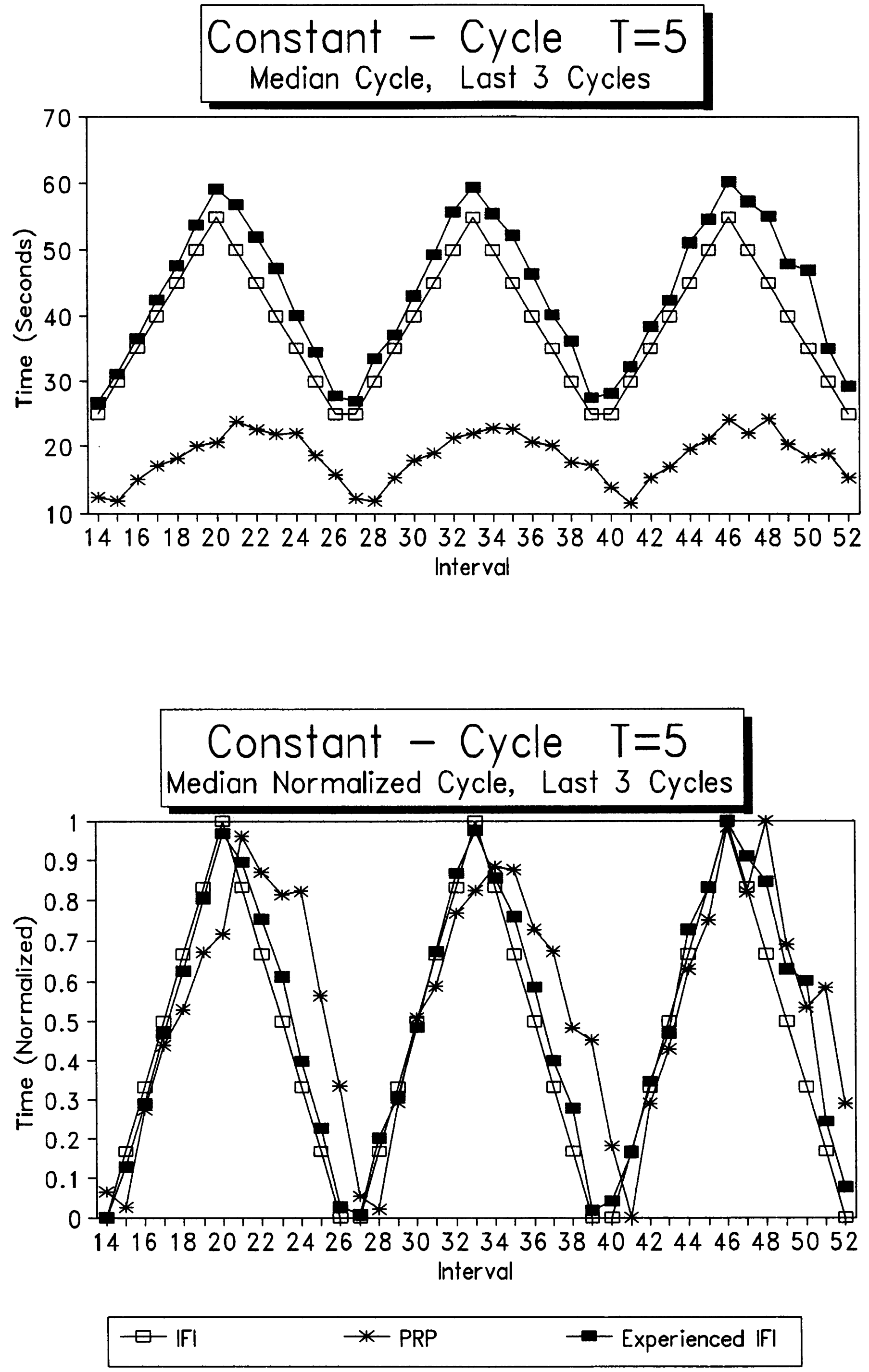


Fig. 3. Top panel: Average postreinforcement pauses (asterisks) during each interval of the last three cycles of the session during the constant-cycle $T = 5$ condition. Data are means of the median PRPs of 4 birds over the last 15 sessions of the condition. The programmed IFIs during which the PRPs occurred (open squares) and the IFIs actually experienced (closed squares) are also shown. Bottom panel: Normalized PRP and IFI cycles. See text for further details.

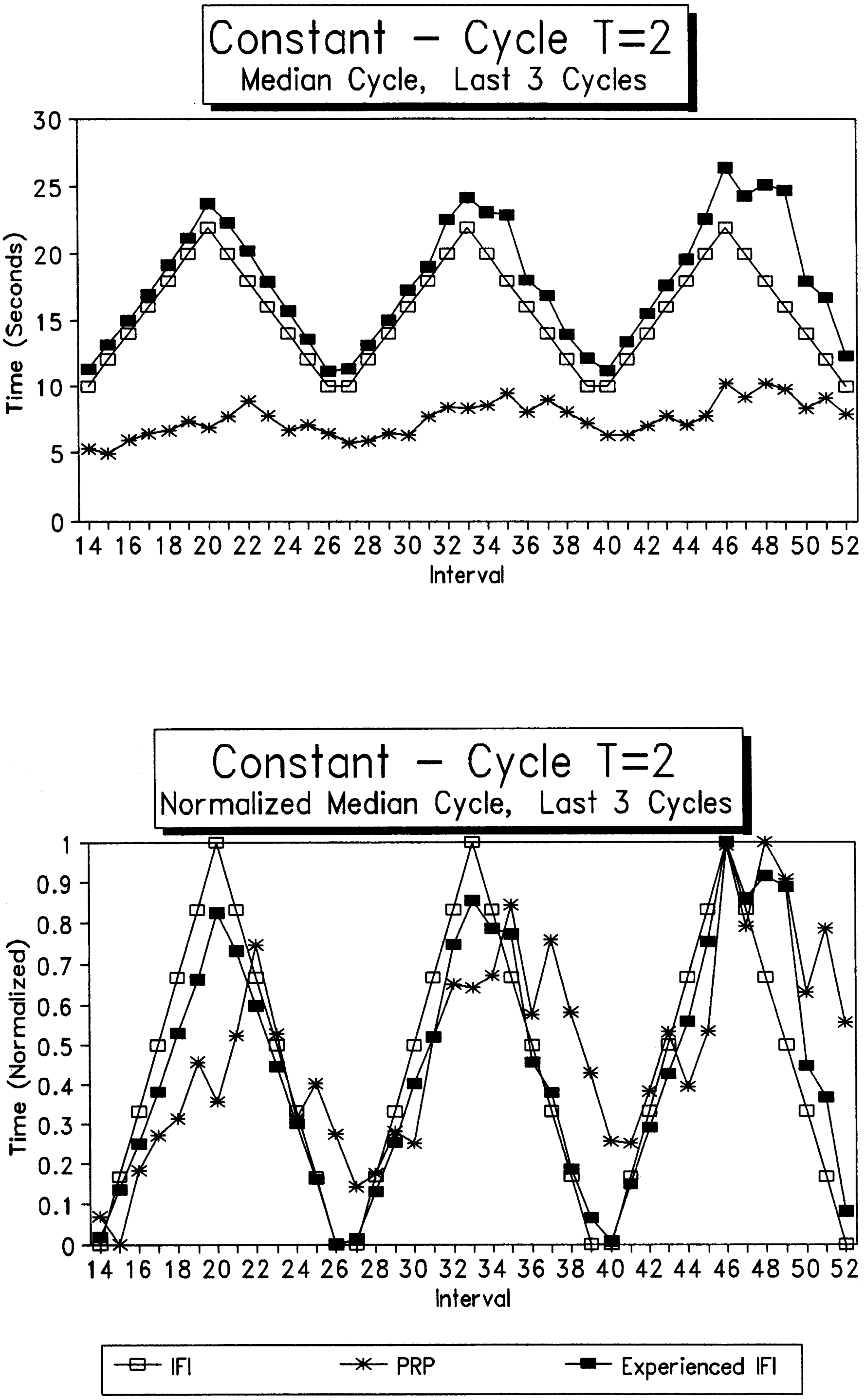


Fig. 4. Top panel: Average PRP and IFI data for each interval of the last three cycles of the session during the constant-cycle $T = 2$ condition. For other details see Figure 3.

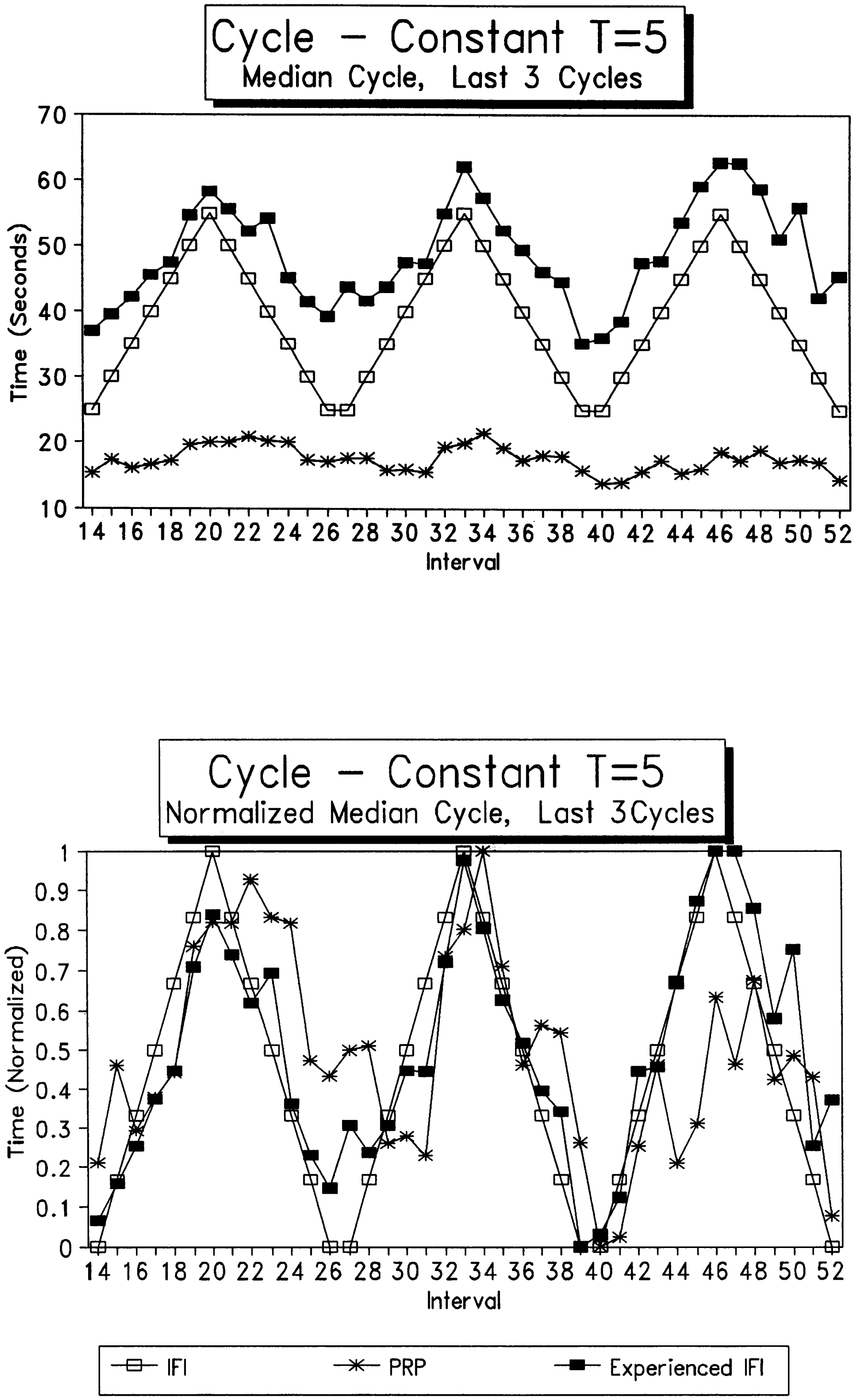


Fig. 5. Top panel: Average PRP and IFI data for each interval of the last three cycles of the session during the cycle-constant $T = 5$ condition. For other details see Figure 3.

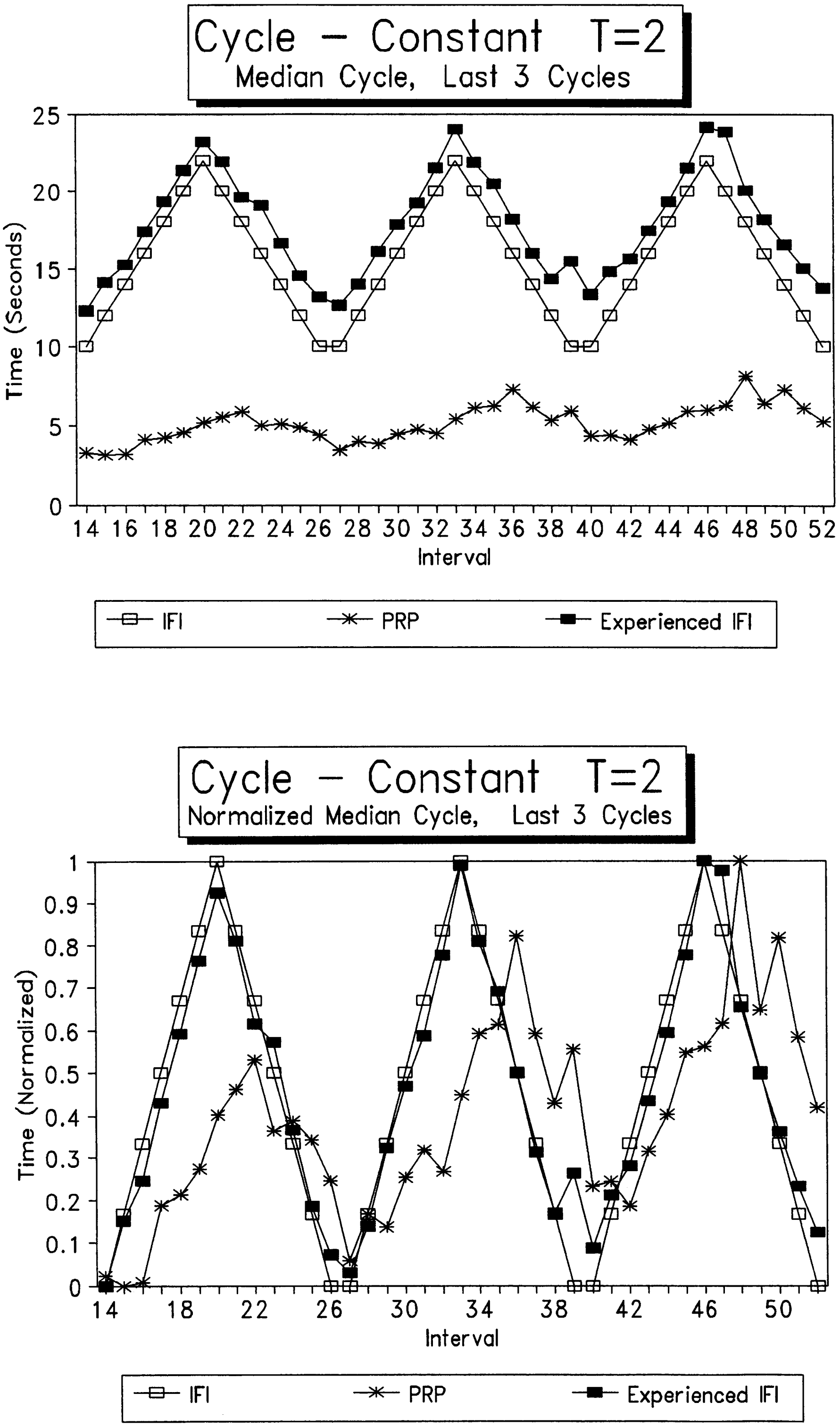


Fig. 6. Top panel: Average PRP and IFI data for each interval of the last three cycles of the session during the cycle-constant $T = 2$ condition. For other details see Figure 3.

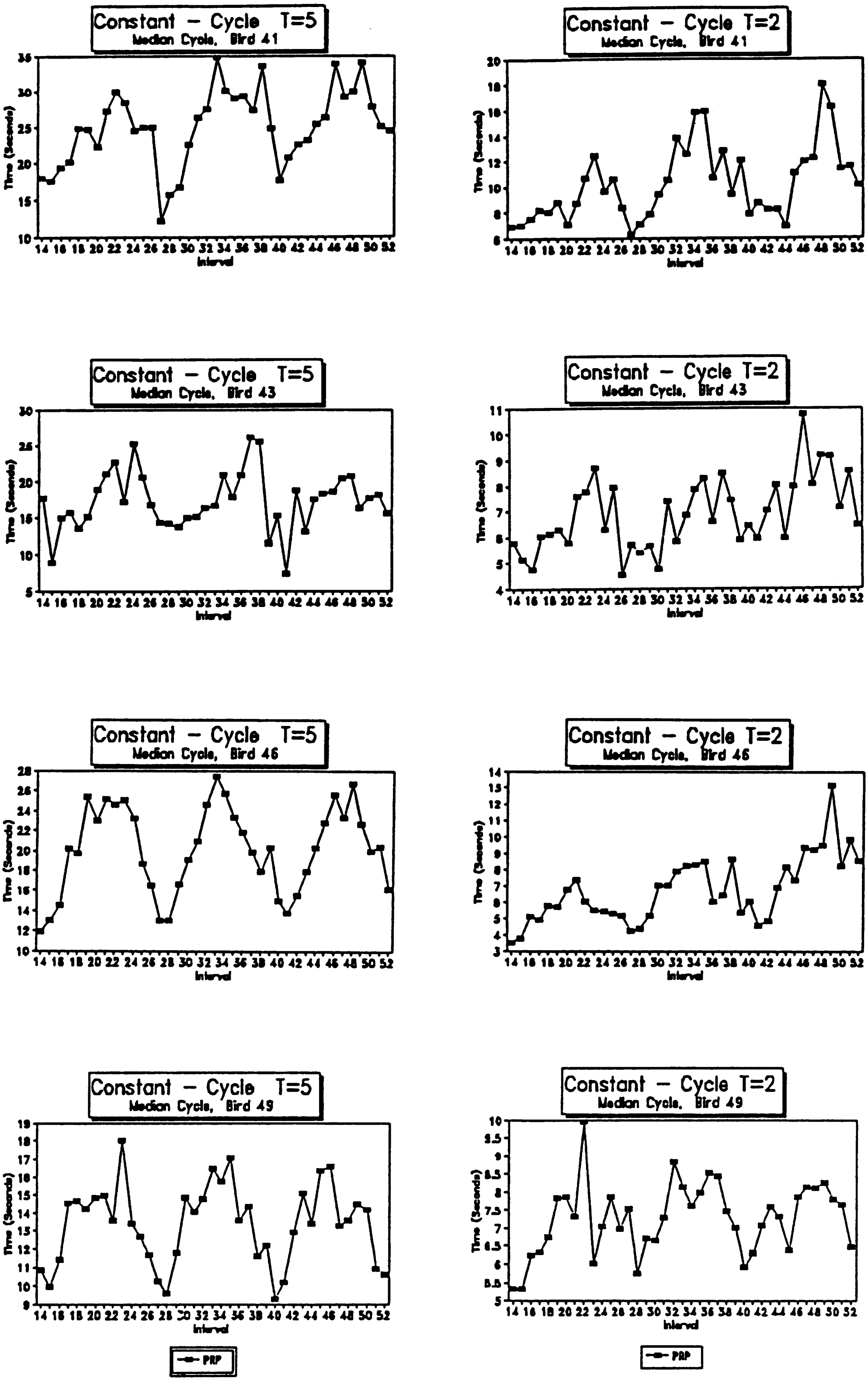
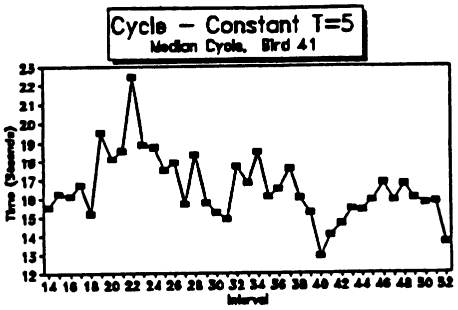
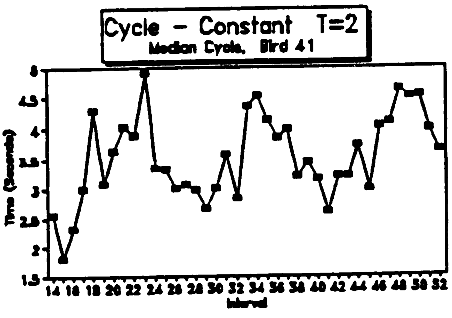
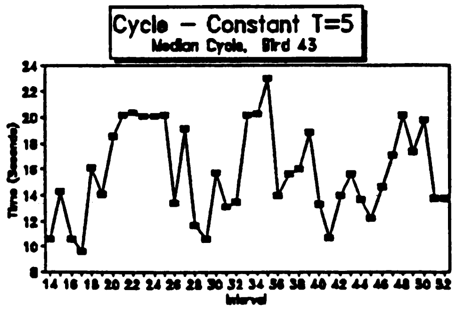
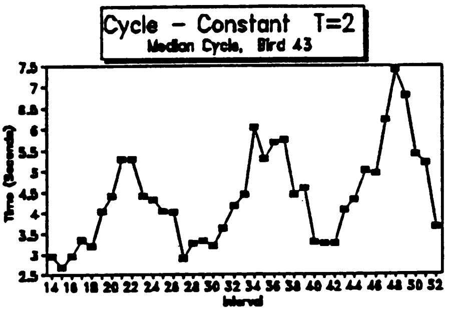


Fig. 7. Individual data for the 4 subjects on the constant-cycle schedules. The $T = 5$ condition is shown at the left, and the $T = 2$ condition is shown at the right. The last three cycles shown in these figures are the median pause data that comprise Figures 3 and 4.


Cycle – Constant T=5
Median Cycle, Bird 41
Time (Seconds)
23 22 21 20 19 18 17 16 15 14 13 12
14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Interval


Cycle – Constant T=2
Median Cycle, Bird 41
Time (Seconds)
5 4.5 4 3.5 3 2.5 2 1.5
14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Interval


Cycle – Constant T=5
Median Cycle, Bird 43
Time (Seconds)
24 22 20 18 16 14 12 10 8
14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Interval


Cycle – Constant T=2
Median Cycle, Bird 43
Time (Seconds)
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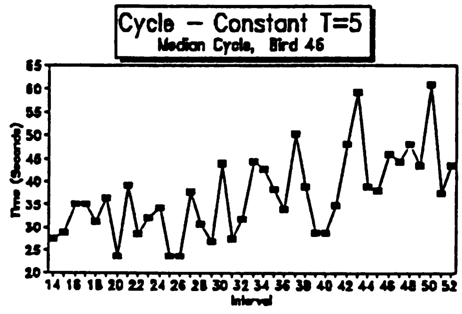
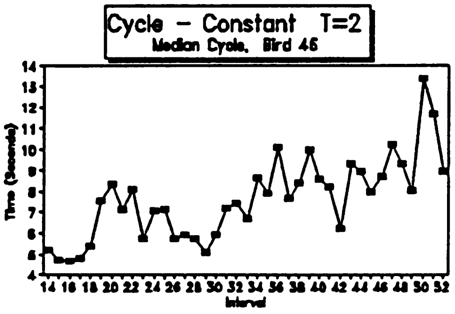
14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Interval


Cycle – Constant T=5
Median Cycle, Bird 46
Time (Seconds)
65 60 55 50 45 40 35 30 25 20
14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Interval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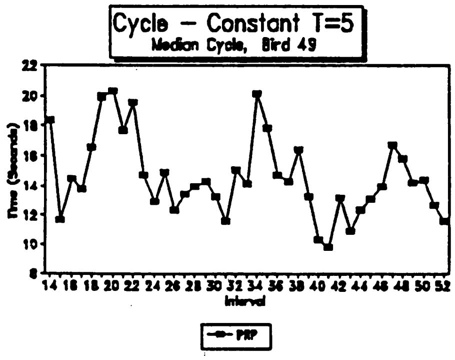
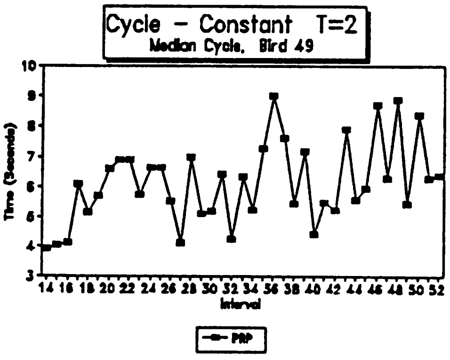
Median Cycle, Bird 46
Time (Seconds)
14 13 12 11 10 9 8 7 6 5 4
14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Interval


Cycle – Constant T=5
Median Cycle, Bird 49
Time (Seconds)
22 20 18 16 14 12 10 8
14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Interval
PRP


Cycle – Constant T=2
Median Cycle, Bird 49
Time (Seconds)
10 9 8 7 6 5 4 3
14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Interval
PRP

phase lags. Table 2 shows these correlations, computed using data from the 4 birds averaged across the sessions plotted in Figures 3 through 6 for the four conditions of Experiment 1. The PRP in a given interval was positively correlated with the experienced duration of that IFI (Lag 0), and with interval durations experienced one, two, and three intervals back. In general, correlations were highest at phase Lags 1 and 2: for the $T = 5$ conditions the highest correlations were at Lag 1, whereas for the $T = 2$ conditions they were at Lag 2. These data suggest that PRPs are controlled by preceding IFIs rather than by some anticipatory process.

Table 2

Postreinforcement pause (PRP) correlated with IFI for Experiments 1 and 2.

Condition	Lag 0	Lag 1	Lag 2	Lag 3
Constant-cycle $T = 5$	.84 $p < .01$	.94 $p < .01$	.81 $p < .01$	.48 $p < .05$
Constant-cycle $T = 2$	.58 $p < .01$	.77 $p < .01$	.80 $p < .01$	.60 $p < .01$
Cycle-constant $T = 5$	.66 $p < .01$	.71 $p < .01$	.62 $p < .01$	.49 $p < .04$
Cycle-constant $T = 2$	.46 $p < .06$	.66 $p < .01$	.79 $p < .01$	.66 $p < .01$
Experiment 2		.13 $p < .38$	.44 $p < .01$	.22 $p < .12$

Within-Cycle Comparison of PRPs

Difference scores were computed to look at the relationship of PRPs associated with intervals of the same duration in the ascending and descending portions of a cycle. These data may also help us to differentiate between the one-back linear waiting theory (control by the preceding interval) and any type of anticipation of upcoming intervals, as would occur if the birds learned the serial pattern of the IFIs. Difference scores for a particular cycle were computed by subtracting the PRP during an IFI in the descending portion of the cycle from the PRP during the IFI of the same duration in the ascending series. So, for example, the PRP in the 15-s interval on the descending portion of the cycle was subtracted from the PRP in the 15-s ascending interval. If the PRPs during corresponding intervals are equal, the difference score will be zero, indicating that the PRP is determined by the current interval value. We might conclude from this that the birds had learned something about the pattern of the intervals and were anticipating their duration. If the pause in the ascending interval is longer, the difference score will be positive, also suggesting that the bird could be anticipating impending intervals (longer on the ascending and shorter on the descending limbs). On the other hand, if the pause during the ascending interval is shorter, the difference score will be negative, indicating control by preceding intervals.

The median difference scores were calculated over the last three cycles and last 15 days in each condition for each subject. There are 18 difference scores (six from each cycle) for each session. Figures 9 and 10 show the individual difference scores in the constant-cycle and cycle-constant conditions, respectively. For the most part, difference scores were negative, indicating control by recently preceding IFIs rather than by a prospective process in which the birds were anticipating upcoming intervals.

In summary, postreinforcement pauses tracked cyclically changing IFI durations in both the constant-cycle and cycle-constant conditions and at both values of T. Because temporal tracking occurred in both of these conditions (i.e., regardless of the ordering of the two components), there is support for the conclusion that food presentation, rather than delay-stimulus onset, is the time marker controlling PRPs on these schedules. Both correlational and difference-score data suggest that pause durations are determined largely by recently preceding IFIs.

EXPERIMENT 2

The results of the first experiment support the idea that the duration of the PRP on cyclic-interval schedules is determined by IFI du-

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Fig. 8. Individual data for the 4 subjects on the cycle-constant schedules. The $T = 5$ condition is shown at the left, and the $T = 2$ condition is shown at the right. The last three cycles shown in these figures are the median pause data that comprise Figures 5 and 6.

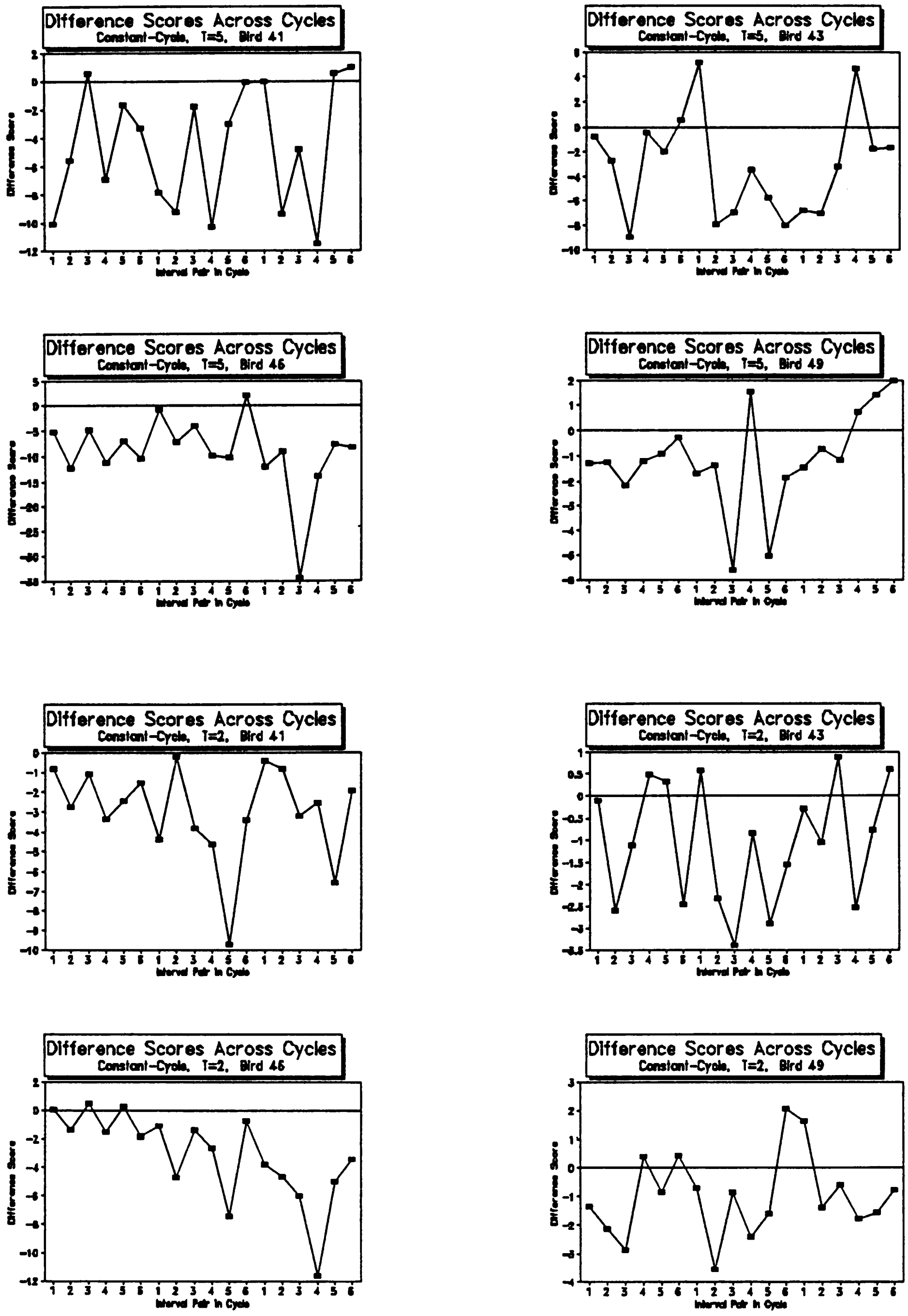

Fig. 9. Difference scores for all birds during the constant-cycle condition. See text for details.

ration. Because cyclic changes in PRPs occurred when the second component was constant, we can reject the constant component as a determinant of the PRP under these conditions. However, we cannot reject entirely the role of the cyclic component on the schedules studied, because either the IFI or the duration of the cyclic component could be implicated in a cyclic pattern of PRPs. The procedure of Experiment 1 did not permit us to distinguish

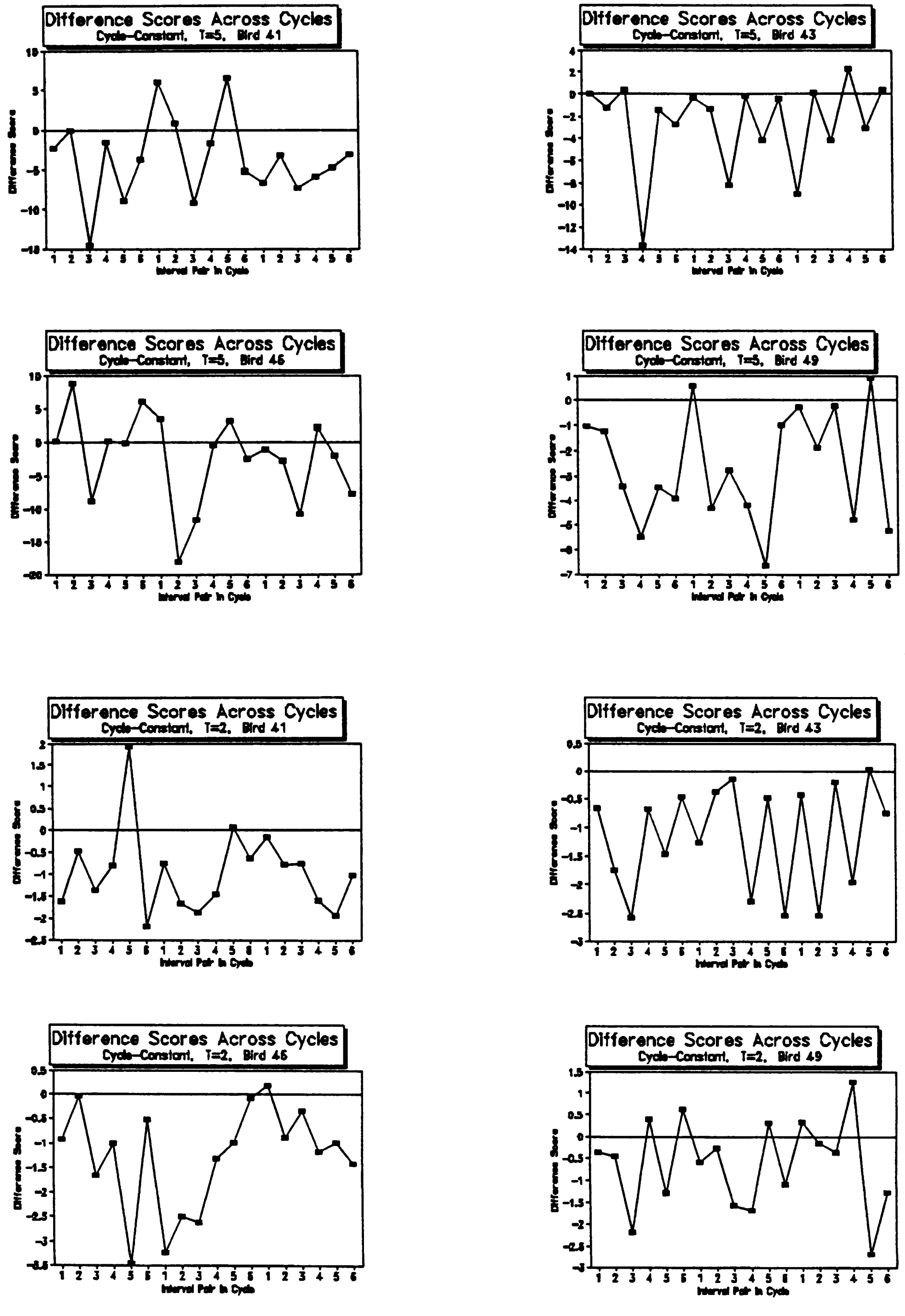

Fig. 10. Difference scores for all birds during the cycle-constant condition. See text for details.

clearly between the effects of total IFI and the cyclic component. Experiment 2 addressed this problem.

In this study, the IFI was held constant while the two components comprising it were allowed to change cyclically. As before, a two-component chained schedule was used. The first component was identical to the cyclic component of the $T = 5$ condition of Experiment 1; the second component varied inversely with the first, allowing the IFI to remain constant. The duration of the second component was reduced if the duration of the first component exceeded the programmed duration, in order to keep the total IFI fixed. If the IFI controls the duration of the PRP, pigeons should produce PRPs that are relatively constant and proportional to the constant IFI. Tracking either of the cyclic components would produce different patterns of PRPs, depending on which component is tracked. If the tracking pattern is similar to the patterns seen in the first experiment, the primary component would be implicated. If the PRPs form a pattern that is the inverse of that observed in Experiment 1, the second component, delay to reinforcement, would be involved.

METHOD

Subjects and Apparatus

The birds from Experiment 1 were used in this study. The apparatus was the same as in Experiment 1.

Procedure

All 4 birds received a procedure similar to the cycle-constant $T = 5$ condition experienced in Experiment 1. The programmed first component was identical to the cyclic component of this condition, with intervals increasing in 5-s steps from 5 to 35 s and then decreasing to 5 s. However, the second component cycled in the reverse direction to the first (35 to 5 to 35 s). Figure 11 illustrates the cyclic-cyclic programmed input for Experiment 2. In addition, when a response did not occur until after the first component had timed out, extending its duration, the second component was reduced by the excess. In this manner, the IFI was fixed at 40 s. The keylight during the first component was the same color as the cyclic component experienced by each bird during the last phase of Experiment 1. The birds were exposed to this schedule for 20 sessions.

RESULTS AND DISCUSSION

Figure 12 presents the PRP data for each of the 4 pigeons for Experiment 2. As in the previous study, data from the first 13 intervals of the session are not presented. Although there are individual differences across birds, 3 of the 4 birds clearly paused for about the same duration during all intervals. There is, perhaps, some cyclicity in the pattern of Bird 43. Overall, then, these data tend to support the view that total IFI, rather than delay to food or the duration of the initial cycle, is the main factor controlling pauses. A comparison of the PRP data with the first-component input cycles (fine lines in Figure 12) shows that during many intervals the birds did not make their first pecks until well after this component had timed out. In these intervals the first peck produced the stimulus change, and the second component was reduced in duration, maintaining the constant IFI. The experienced IFI was typically about 0.5 s longer than the programmed interval, indicating that the peck producing access to food usually occurred immediately after the interval timed out.

Overall, PRPs for each subject were quite consistent throughout the session. Although the average pause was about 12.59 s and did not vary in any systematic way with either of the cyclic-interval components for 3 of the 4 birds, 2 birds paused considerably longer than the other 2. The difference between these pairs suggests that the conditions experienced during the final sessions of Experiment 1 were still exerting some effect on performance. Birds 41 and 46, who paused much longer than Birds 43 and 49, were switched from the $T = 5$ schedules. The other birds' most recent experience was with $T = 2$ schedules (see Table 1). Effects of the previous condition, cycle-constant $T = 2$, may also have contributed to the slight degree of cycling in Bird 43's performance.

Although the experienced differences in interval duration were very small across successive intervals, correlations between PRPs and IFI were determined, as in the previous study, for the data shown in Figure 11; the correlation coefficients are presented in Table 2. All the correlations are small, and only one is statistically significant.

GENERAL DISCUSSION

The experiments reported here examined the factors controlling postreinforcement pausing on cyclic-interval schedules of food presentation. Our main concern was to examine whether IFI duration or the delay to food following the onset of a stimulus temporally contiguous with food was the controlling variable. The results of both Experiments 1 and 2 support the view that PRPs on the schedules ex-

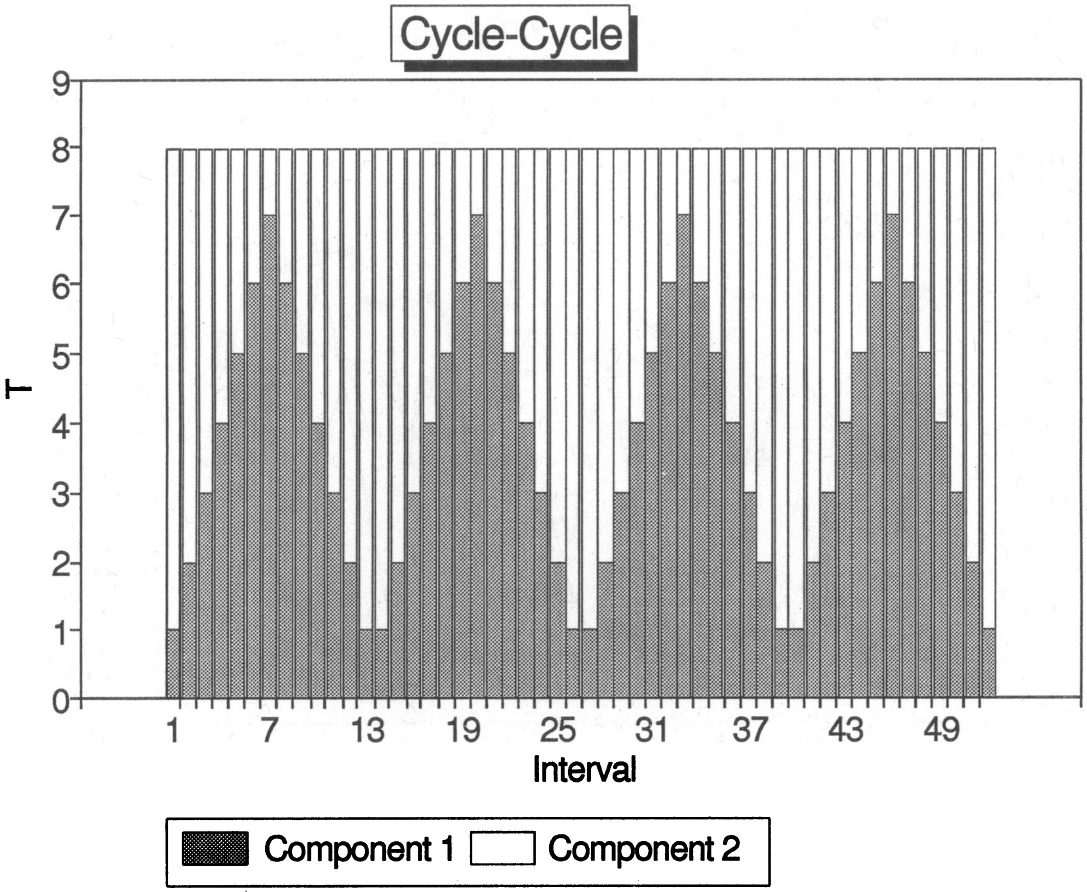

Fig. 11. Schematic representation of the cycle-cycle schedule used in Experiment 2, indicating the programmed durations of the two cyclic components of interfood intervals (IFIs).

amined were determined largely by IFI duration rather than by the onset of the stimulus signaling a delay to food presentation. In Experiment 1, temporal tracking was observed both when the delay to food (Component 2) was constant and when it was cyclic. And a comparison of performance in Experiments 1 and 2 shows that average pauses were essentially constant when the IFI was constant, but tracked the changing intervals when IFIs of several different durations were programmed. Although the effect of the work period (time since the first peck in an interval) was not directly examined here, Innis, Cooper, and Mitchell (in press), in a similar study, found very low correlations between work period and the subsequent PRP. The results of Experiment 1 also suggest that the birds did not learn something about the pattern of IFIs in a cycle, because their PRPs showed no evidence of anticipation of upcoming interval durations.

Although there is support for the view that PRPs are controlled by the duration of preceding IFIs and therefore for the linear waiting hypothesis, it is less clear that pauses are controlled by only the immediately preceding IFI, as Wynne and Staddon (1988) proposed. However, the initial linear waiting account was based on data obtained with RID schedules in which only a single delay occurred in a given session and only very short IFIs were programmed. Wynne and Staddon (1992) looked at performance on schedules with longer IFIs and suggested that waiting time may be influenced by more than the preceding interval. Moreover, in situations using the RID procedure in which several delay values occurred (e.g., Higa et al., 1991), results more

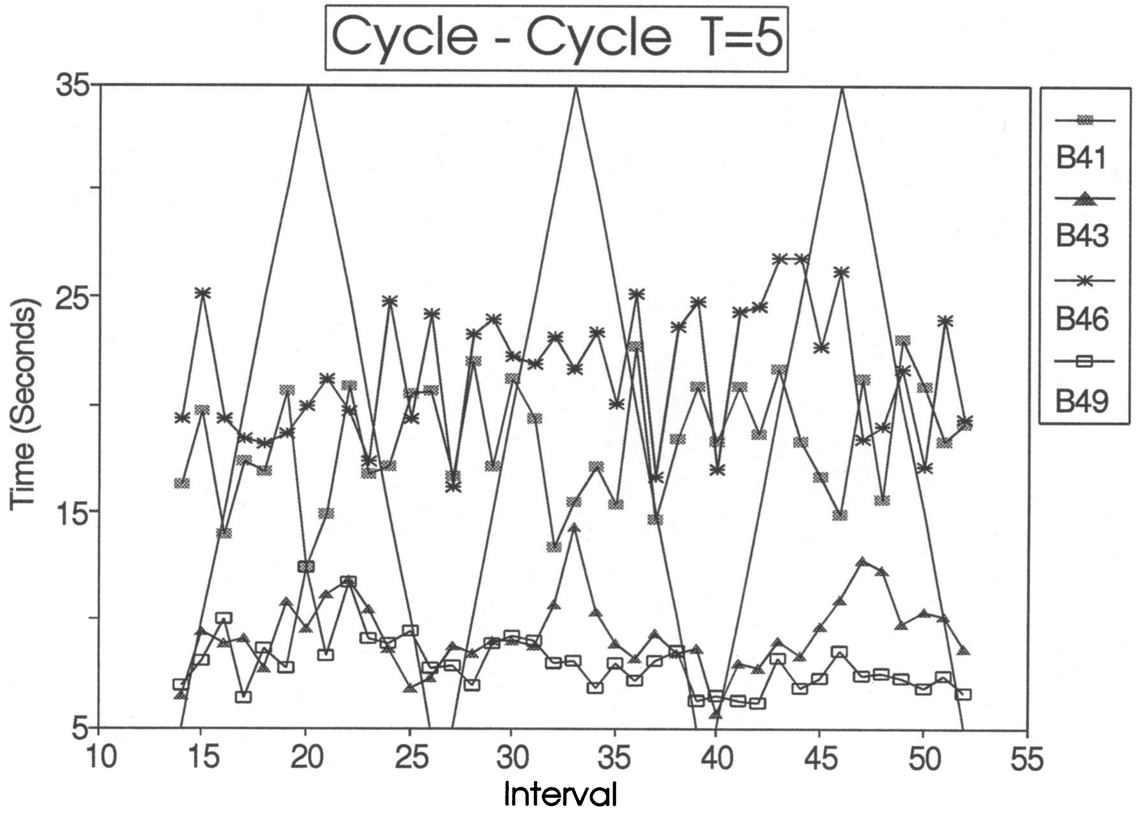

Fig. 12. Median postreinforcement pauses for each of the 4 birds during each interval of the last three cycles of the session in Experiment 2. The programmed IFIs for the first (cyclic) component are also shown.

similar to those reported here were obtained. Innis et al. (in press), using schedules very similar to the ones studied here, also report similar findings. All these data suggest that PRPs during a given interval may be determined by more than one preceding IFI and, therefore, support a somewhat modified linear waiting hypothesis.

The average PRPs during many intervals of the cyclic schedules in the present study were much shorter than those reported for the same IFIs on simple FI schedules. During the $T = 5$ condition, when IFIs ranged from 25 to 55 s, PRPs were never greater than about one third of the longest IFI (see the upper panels in Figures 3 through 6). Pauses on the schedules with the shorter intervals ($T = 2$ condition) were closer to the appropriate values, but temporal control was still degraded. This finding is similar to that reported for performance on other cyclic-interval schedules (e.g., Innis & Staddon, 1971). During Experiment 2, 2 birds paused for about half the 40-s IFI; however, the other 2 subjects displayed very short pauses. These differences are likely related to the previous condition under which they were studied.

The degradation of control on cyclic schedules and the persistent influence of preceding conditions suggest that the PRP on FI schedules is not the result of a simple one-back process. At least two processes may be involved: The first—obligatory linear waiting—develops rapidly, and may be determined primarily by the duration of the just-preceding IFI. A second process may develop more slowly and depend on a much larger array of past experience and environmental stimuli (see also Innis & Honig, 1979).

REFERENCES

Ferster, C. B., & Skinner, B. F. (1957). *Schedules of reinforcement.* New York: Appleton-Century-Crofts.

Gibbon, J. (1977). Scalar expectancy theory and Weber's law in animal timing. *Psychological Review,* **84,** 279–325.

Harzem, P. (1969). Temporal discrimination. In R. M. Gilbert & N. S. Sutherland (Eds.), *Animal discrimination learning* (pp. 299-334). London: Academic Press.

Higa, J. J., Wynne, C. D. L., & Staddon, J. E. R. (1991). Dynamics of time discrimination. *Journal of Experimental Psychology: Animal Behavior Processes,* **17,** 281-291.

Hulse, S. H., & Dorsky, N. P. (1979). Serial pattern learning by rats: Transfer of a formally defined stimulus relationship and the significance of nonreinforcement. *Animal Learning & Behavior,* **7,** 211-220.

Innis, N. K. (1970). *Temporal tracking on cyclic-interval reinforcement schedules.* Unpublished doctoral dissertation, Duke University.

Innis, N. K. (1981). Reinforcement as input: Temporal tracking on cyclic interval schedules. In M. L. Commons & J. A. Nevin (Eds.), *Quantitative analyses of behavior: Vol. 1. Discriminative properties of reinforcement schedules* (pp. 257-286). New York: Ballinger.

Innis, N. K., Cooper, S. J., & Mitchell, S. K. (in press). The determinants of postreinforcement pausing. *Behavioural Processes.*

Innis, N. K., & Honig, W. K. (1979). Stimulus control of behavior during the postreinforcement pause of FI schedules. *Animal Learning & Behavior,* **7,** 203-210.

Innis, N. K., & Staddon, J. E. R. (1971). Temporal tracking on cyclic-interval reinforcement schedules. *Journal of the Experimental Analysis of Behavior,* **16,** 411-423.

Killeen, P. R., & Fetterman, J. G. (1988). A behavioral theory of timing. *Psychological Review,* **95,** 274-295.

Schneider, B. A. (1969). A two-state analysis of fixed-interval responding in the pigeon. *Journal of the Experimental Analysis of Behavior,* **12,** 677-687.

Shull, R. L. (1970). The response-reinforcer dependency in fixed-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* **14,** 55-60.

Shull, R. L. (1971). Sequential patterns in post-reinforcement pauses on fixed-interval schedules of food. *Journal of the Experimental Analysis of Behavior,* **15,** 221-231.

Staddon, J. E. R., & Higa, J. J. (1991). Temporal learning. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (pp. 265-294). San Diego: Academic Press.

Staddon, J. E. R., Wynne, C. D. L., & Higa, J. J. (1991). The role of timing in reinforcement schedule performance. *Learning and Motivation,* **22,** 200-225.

Wynne, C. D. L., & Staddon, J. E. R. (1988). Typical delay determines waiting time on periodic-food schedules: Static and dynamic tests. *Journal of the Experimental Analysis of Behavior,* **50,** 197-210.

Wynne, C. D. L., & Staddon, J. E. R. (1992). Waiting in pigeons: The effects of daily intercalation on temporal discrimination. *Journal of the Experimental Analysis of Behavior,* **58,** 47-66.

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