EFFECTS OF A SIGNED DELAY TO REINFORCEMENT IN THE PREVIOUS AND UPCOMING RATIOS ON BETWEEN-RATIO PAUSING IN FIXED-RATIO SCHEDULES

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Domestic hens responded under multiple fixed-ratio fixed-ratio schedules with equal fixed ratios. One component provided immediate reinforcement and the other provided reinforcement after a delay, signaled by the offset of the key light. The components were presented quasirandomly so that all four possible transitions occurred in each session. The delay was varied over 0, 4, 8, 16, and 32 s with fixed-ratio 5 schedules, and over 0, 8 and 32 s with fixed-ratio 1, 15 and 40 schedules. Main effects of fixed-ratio value and delay duration were detected on between-ratio pauses. Pauses were longer when the multiple-schedule stimulus correlated with a delayed-reinforcer component was presented, with the longest pauses occurring at the transition from a component with an immediate reinforcer to one with a delayed reinforcer. Pause durations were shortest during immediate components. Overall, both the presence or absence of a delay in the upcoming component, and the presence or absence of a delay in the preceding component affected pause length, but the upcoming delay had the larger effect. Thus changes in delay had similar effects to past reports of the effects of changes in response force, response requirement, and reinforcer magnitude in multiple fixed-ratio fixed-ratio schedules.

Key words: fixed-ratio schedules, multiple schedules, delay to reinforcement, post-reinforcement pause, pre-ratio pause, between-ratio pause, key peck, domestic hens

Responding under fixed-ratio (FR) schedules is characterized by a pause followed by a constant rate of responding. The pause was first described by Ferster and Skinner (1957) as 'the pause after reinforcement', but soon became known as the 'post-reinforcement pause'. Although this term may be descriptive, some researchers believe that it suggests an erroneous relation between the pause and the previously completed ratio (Griffiths & Thompson, 1973). Many researchers suggest that the pause may actually be a function of the upcoming ratio, or a combination of the preceding and upcoming ratios (Baron & Herpolsheimer, 1999; Crossman, 1968; Griffiths & Thompson, 1973; Inman & Cheney, 1974; Mintz, Mourer & Gofseyeff, 1967; Perone & Courtney, 1992; and Wade-Galuska, Perone & Wirth, 2005). These pauses after

reinforcement are referred to here as the between-ratio pauses.

The between-ratio pause increases in duration with an increase in FR size (e.g., Felton & Lyon, 1966), with a decrease in reinforcer magnitude (e.g., Lowe, Davey, & Harzem, 1974; Powell, 1969), and with an increase in delay to the reinforcer (e.g., Morgan, 1972). However, it is not clear how the pause duration is influenced by the parameters of the preceding and upcoming schedule because, in these FR studies, the response requirement was held constant over a session.

Multiple FR FR schedules, in which two (or more) ratios are presented, each associated with a different stimulus, can be used to investigate the effects of the preceding and upcoming schedule parameters on pausing. They have been used to study the effects of FR size (e.g., Baron & Herpolsheimer, 1999), reinforcer magnitude (e.g., Perone & Courtney, 1992), and force requirement (Wade-Galuska et al., 2005). Some studies have alternated the FR schedules (Crossman, 1968; Inman & Cheney, 1974; Mintz et al., 1967). Others have presented them according to a quasirandom sequence (Baron & Herpolsheimer, 1999; Griffiths & Thompson, 1973; Perone & Courtney, 1992; and Wade-Galuska et al., 2005), thus giving four different transitions between FRs.

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Examining FR size, Crossman (1968) alternated the FR schedules across multiple-schedule components and found the pauses preceding a large response requirement were longer than those preceding a small one. His subjects were exposed to only large-small and small-large FR schedule transitions and so the effects of the preceding FR schedule requirement were unclear. Inman and Cheney (1974) alternated different size FR schedules up to the final six sessions of their experiment and reported increased pause durations preceding larger FR values, and that pausing after the requirement was not affected by FR size. Mintz *et al.* (1967) alternated pairs of FR schedules (large-large-small-small) to expose the subjects to the four possible transition types. Their findings suggested that pausing was influenced by the size of both the upcoming and preceding ratios. These authors noted that these results cannot be explained by fatigue, for if pause duration was due to fatigue, then it should be longer after, not before, the large FR. Results from studies that presented the two FR schedules quasirandomly (Baron & Herpolsheimer, 1999; Griffiths & Thompson, 1973; Perone & Courtney, 1992; and Wade-Galuska *et al.*, 2005) have supported the finding that pausing in multiple FR FR schedules is most influenced by the size of the upcoming FR, but also somewhat influenced by the size of the previous FR.

Similar results have been found when the effects of reinforcer magnitude and the effort required to make a response are examined. In a second experiment, also with multiple FR FR schedules, Inman and Cheney (1974) found that the pauses preceding the large response requirement decreased in duration with increasing reinforcer magnitude. Similarly, Perone and Courtney (1992) found that between-ratio pauses were shorter before large reinforcers than before small reinforcers and were longer after large reinforcers than after small reinforcers. Thus pausing was a function of both the previous reinforcer size and the stimulus signaling the upcoming reinforcer. Wade-Galuska *et al.* (2005) used quasirandomly sequenced multiple FR FR schedules and manipulated the force required to operate response levers. They found that pauses were longer when the upcoming component was associated with a large force and longer still when the previous force was small. They

conceptualized the increase in force as conditions having become 'more unfavorable'.

Thus, the effects of increasing the ratio requirement, decreasing reinforcer magnitude and increasing effort on between-ratio pauses have been found to be similar. Increases in these three parameters could all be regarded as producing 'more unfavorable' conditions by reducing reinforcer effectiveness.

As yet, the effects of delay to reinforcement on FR responding have not been studied using multiple schedules. Increasing the delay to reinforcement might be regarded as another means of reducing reinforcer effectiveness as previous studies have shown that increasing the delay to reinforcement increases pausing in singly presented FR schedules (Morgan, 1972). If delay has an effect on pausing comparable to changes in ratio size, reinforcer magnitude and effort, then signaling a longer upcoming delay to reinforcement should increase the duration of between-ratio pauses, with the longest pauses occurring at transitions from brief to long delays. Such a finding would demonstrate that pausing is a function of both the previous delay to reinforcement and the stimulus signaling the upcoming delay.

To test this hypothesis, in the present experiment a signaled, nonresetting delay to the reinforcer was added to one component of multiple FR FR schedules. In each condition, the FR schedules in both components were held constant and the two components were sequenced quasirandomly so that all four possible transitions between components occurred. Across conditions, we varied the FR schedule and the duration of the delay to reinforcement.

METHOD

Subjects

The 6 subjects, numbered 61 through 66, were Shaver-Starcross domestic hens (*gallus gallus domesticus*). At the beginning of the experiment, the hens were 2 yrs old, and had had some experience on simple schedules of reinforcement. The hens were housed individually in home cages (500 mm long $\times$ 510 mm wide $\times$ 420 mm high), in a ventilated room on a 12-hr light:12-hr dark cycle. They had free access to water, and grit and vitamins were provided weekly. Throughout the experiment

all hens had red fleshy combs suggesting good health. Each hen was weighed every day the experimental sessions took place (approximately 6 days per week) and they were maintained at 80% (+/-5%) of their free feeding body weights through feeding of commercial layer pellets.

Apparatus

The apparatus was a particleboard experimental chamber (640 mm long $\times$ 450 mm wide $\times$ 580 mm high), located in a room with several other experimental chambers. The chamber floor was covered with a thick metal grid (30 mm $\times$ 30 mm) enclosed in a steel tray. A food magazine was located on the right-hand wall of the chamber behind an opening (115 mm high $\times$ 70 mm wide) that was centered 105 mm above the floor. When operational, the magazine was lit and raised to allow 3-s access to wheat. Above the magazine opening (390 mm from the floor) was a frosted transparent plastic response key (30 mm in diameter), which could be lit red and green with a 28-V multichip LED bulb, and that required a force of approximately 0.2 N, resulting in an audible beep.

All experimental events were recorded and the experiment was controlled by a Dell PC computer (1.6GHz, P4, 256MB, Windows XP Service Pack 2) running Med-PC[®] IV software. Total session data were also manually recorded into a data book at the end of each session.

Procedure

Multiple schedules. The response key could be lit red or green, each color being associated with one component of the multiple schedule. There were four different sequences of light changes which could occur within a session, red-red (RR), red-green (RG), green-green (GG), and green-red (GR). In order to ensure that all four transitions occurred within a session, the order in which these lights were presented (including the initial key color at the start of a session) was determined by a quasirandom order based on the Gellerman (1933) sequence. This sequence also ensured that the same schedule (and key color) was not presented more than three consecutive times.

In all conditions, subjects were given 3-s access to wheat when the requirements of the schedule were completed. During the delivery

of the reinforcer, the key light was extinguished and the food magazine was lit and raised. Immediately following reinforcement, the key was relit. Sessions ended (and the key light was extinguished) when 40 reinforcers had been delivered, or after 40-min key-time. Data were discarded if fewer than 20 reinforcers had been obtained or if an egg had been laid during the session.

All hens were exposed to the same number of sessions in each condition. Each condition lasted until median pause durations (i.e., the time from the end of reinforcement to the first response on the next schedule) were considered stable over the most recent 10 sessions using the following criteria (see Perone & Courtney, 1992; also, Baron & Herpolsheimer, 1999). For each session, the median pause lengths were calculated for each of the four transitions. First, a plot of the medians over sessions had to show that there were no visual increasing or decreasing trends across the last 10 sessions. In addition, the medians of the first five and the second five sessions of the last 10 sessions were required to differ from the overall median from the last 10 sessions by no more than 15%. If 50 sessions had been conducted then the conditions were changed once the visual stability criterion had been met, even when the statistical criterion had not been met.

Training. Hens 61, 62, 64, 65 and 66 required only one session of training in which a reinforcer was manually delivered after every one or two responses for the first 10 to 20 reinforcers. When the hens were responding to the lighted response key consistently, each hen completed a session that ended after 40 reinforcers were delivered according to a multiple FR 5 FR 5 schedule. For Hen 63, an additional day of training was required, in which she was trained to peck the response key using the method of successive approximations. The key light was the only illumination in the chamber. During magazine operation, the key light was extinguished and the hopper was lit and raised.

Equal FR schedules were in effect during both components in all conditions. As shown in Table 1, the FR requirement was varied from 1 to 40 across conditions. In the first condition at each new FR value, all reinforcers were delivered immediately following the final response of the FR requirement in both

Table 1

The order of experimental conditions, together with the delay duration and the number of sessions each condition was in effect.

Condition	Red Delay (s)	Green Delay (s)	FR	No. of Sessions
1	0	0	5	40
2	4	0	5	28
3	8	0	5	32
4	0	8	5	57
5	16	0	5	44
6	32	0	5	47
7	0	32	5	36
8	0	0	15	56
9	8	0	15	85
10	0	32	15	48
11	0	0	40	44
12	0	8	40	54
13	32	0	40	77
14	0	0	1	35
15	0	8	1	40
16	32	0	1	55

components (0-s delay). In subsequent conditions, a nonresetting delay to the reinforcer was added to one component; delay durations, the sequence of conditions, and number of sessions completed in each condition are shown in Table 1. The delay started on the final response of the FR requirement of that component, was signaled by extinguishing the key light, and ended with the start of magazine operation. The key was relit with the color appropriate to the next component at the end of magazine operation.

Data analysis. Repeated-measures ANOVAs, using General Linear Model (GLM), were conducted to evaluate the effects of delays and FR values on pausing in the four different component types or transitions. The assumption of sphericity was tested for each data set using Mauchly’s test. When this was significant ($p < .05$) the degrees of freedom were adjusted using the Greenhouse-Geisser or Huynh-Feldt correction, as suggested by Field (2009), before determining the significance of the finding. In all cases where this was done, the conclusion was not changed by the use of the correction and so the unadjusted degrees of freedom are reported in the text. The degrees of freedom for the repeated measures ANOVAs are $(k - 1)$ and $(k - 1)(n - 1)$, where k is the number of repeated measures and n is the number of subjects for which all the measures are available. Where the ANOVA was signifi-

cant, pairwise comparisons were used to examine the differences in pause duration across the different transitions. As Field (2009) suggested, Bonferroni confidence interval adjustments were used in testing the significance of these comparisons.

RESULTS

Because there was no systematic difference in behavior across conditions in which the key color was reversed (Conditions 3 and 4 and Conditions 6 and 7), data from the first condition of each pair are presented. As noted earlier, data were not used unless 20 or more reinforcers were obtained. Hen 63 failed to meet this criterion in Conditions 12 and 13 (FR 40 with 8- and 32-s delays) and so no data are presented for this hen for these conditions. Hen 66 was ill and so was withdrawn from the experiment after Condition 12.

Figures 1 and 2 show the distributions of pause durations for Hen 61 during the last 10 sessions of each delay condition. The other hens produced similar distributions. Figure 1 presents the data for the FR 5 conditions. The data shown are the proportions of between-ratio pauses falling in each 1-s interval. Each panel shows data from one type of transition. In the 0-s delay condition, the transitions were RR, RG, GG, and GR. In all other conditions, they were delay–delay (DD), delay–immediate (DI), immediate–immediate (II), and immediate–delay (ID). The data shown in each panel are from the second component listed, that is, the ID data are from Delay components that followed Immediate components.

When there was no delay (0-s delay condition) pausing did not differ consistently across transitions. Generally, there were large numbers of short pauses and comparatively few longer pauses; this resulted in positively skewed distributions. With the added delays, the distributions of pauses in Immediate components (DI and II) generally remained similar to those seen in the 0-s delay condition. In Delay components (DD and ID) there were proportionally more longer pauses and wider distributions of pause durations than in Immediate components (II and DI).

Figure 2 presents the distributions of between-ratio pauses for the remaining conditions (FR 1, FR 15 and FR 40) for Hen 61. For each FR, when there was no delay, the

Fig. 1. The proportions of the total number of between-ratio pauses falling in each 1-s interval plotted against pause duration for all transition types (delay–delay [DD] or red–red [RR]; delay–immediate [DI] or red–green [RG]; immediate–immediate [II] or green–green [GG]; immediate–delay [ID] or green–red [GR]) over the last 10 sessions of the FR 5 conditions for all delays for Hen 61. The last bin shows the proportion of pauses longer than 52 s.

distributions of pauses were similar across all four transition types and tended to be positively skewed. The range of pause durations increased with the FR value. The 0-s delay condition at FR 40 gave more variable pause durations than any other 0-s delay condition for all hens. The addition of a delay resulted in more longer pauses in Delay components (ID and DD) than in Immediate components (DI and II), but the distribution of pauses in Immediate components remained similar to those in the 0-s delay conditions with that FR value. These findings were similar for all hens.

Individual medians and interquartile ranges of the pause durations for each condition are reported in Appendices 1 and 2. These show that the interquartile ranges of the pause durations were generally larger in Delay components (ID and DD) than in Immediate components (DI and II). They also show that the interquartile ranges tended to increase with increasing FR for the 0-s, 8-s and 32-s delay conditions. These findings help confirm that the changes in variability seen in Figures 1 and 2 were present for the other hens.

Fig. 2. The proportions of the total number of between-ratio pauses falling in each 1-s interval plotted against pause duration for all transition types (DD or RR, DI or RG, II or GG, and ID or GR) over the last 10 sessions of the FR 1, 15 and 40 conditions for Hen 61. The last bin shows the proportion of pauses longer than 52 s.

Pause Durations

Figure 3 presents the group mean ($\pm$ one standard deviation) of the median pause durations during the last 10 sessions of the FR 5 conditions. The data are plotted as a function of transition type with delay as a parameter. For the 0-s delay condition, there were no consistent differences in pause durations across transitions between components signaled with different colored key lights ($F(3, 15) = 1.49, p > .05$). However, at all nonzero delays, there was a large main effect of transition type (4 s: $F(3, 15) = 3.38, p < .05$, partial $\eta^2 = .83$; 8 s: $F(3, 15) = 25.44, p < .05$, partial $\eta^2 = .84$; 16 s: $F(3, 15) = 38.98, p < .05$, partial $\eta^2 = .89$; and 32 s: $F(3, 15) = 144.56, p < .05$, partial $\eta^2 = .97$). Post-hoc pairwise comparisons revealed that at all nonzero delays, pauses were significantly longer at DD transitions than at DI or II transitions and at ID transitions than at DI or II transitions (all p values $< .05$). Pauses at II transitions were significantly longer than those at DI transitions for only the 32-s delay condition. Pauses at ID transitions were significantly longer than those at DD transitions for the 8-s and 32-s delay conditions.

Figure 4 presents the group mean ($\pm$ one standard deviation) of the median pause

Fig. 3. The mean of the median between-ratio pause durations (+/- one standard deviation) for the FR 5 conditions plotted as a function of the transition type (DD, DI, II, and ID) for each delay.

durations from the conditions in which a wider range of FR values were explored with fewer delays. The data shown for FR 5 for these delays are the same as those in Figure 3 and for that reason their statistical analysis will not be further discussed. Regardless of delay values shown in the three panels of Figure 4, increasing the FR requirement, in general, produced visually apparent longer pauses in each of the transition-type categories.

For the 0-s delay conditions, there was no significant effect of transition type on pause durations at any FR value (all *p* values > .11). That is, there were no consistent effects of the stimulus color on pause duration. However, for the 8-s and 32-s delay conditions, there were large and significant main effects of transition type on pause duration (all *p* values < .05, all partial η^2 values $\geq$.62). At these delays, and at all FR values, pause duration at DD transitions were significantly longer than those at DI or at II transitions, and pauses at ID transitions were significantly longer than those at II or at DI transitions (these and all subsequent *p* values < .05). Pauses at ID transitions were significantly longer than those at DD transitions for all conditions except FR 40 with 8-s delay. No significant differences between II and DI pause durations were detected.

Fig. 4. The mean of the median between-ratio pause durations (+/- one standard deviation) for the 0-s, 8-s and 32-s delay conditions plotted as a function of transition type (DD or RR, DI or RG, II or GG, and ID or GR) for each FR.

Running-Response Rates

The median and the interquartile ranges of the running-response rates in each component over the last 10 sessions of all conditions are given in Appendices 3 and 4. Note that running-response rates, defined as the rate of responding between the first and last response in the ratio run, cannot be calculated for the FR

Fig. 5. The mean of the median running-response rates (per s) ($\pm$ one standard deviation) for the FR 5 conditions plotted as a function of the transition type (DD, DI, II, and ID) for each delay. The data for each delay have been offset for visibility.

1 conditions. Figure 5 shows the group mean ($\pm$ one standard deviation) of the median running rate data for each transition type from the FR 5 conditions, with delay as a parameter. When there was no delay, running-response rates did not differ across components. When there was a delay, mean running-response rates slowed predominantly when the upcoming reinforcer would be delayed (DD and ID). This finding was true for all hens and conditions, except for Hens 61 and 66 in the 4-s delay condition and Hen 62 in the 16-s and 32-s delay conditions (Appendix 3). Mean running-response rates did not decrease systematically as delay increased for any transition type.

Figure 6 shows the group mean ($\pm$ one standard deviation) of the median running-response rates for the 0-s, 8-s and 32-s conditions. When there was no delay (top panel), mean running-response rates decreased with increases in FR value but were similar across components for any FR value. When there was a delay (middle and bottom panels), running-response rates tended to be lower in Delay components (DD and ID) than in Immediate components (DI and II) for each FR, and they decreased with increases in FR value. Individual hens' median running-response rates (Appendix 4) followed both of these patterns. In the FR-15 condition, the running-response rates with the 0-s delay (top

Fig. 6. The mean of the median running response rates (per s) ($\pm$ one standard deviation) for the 0-s, 8-s and 32-s delay conditions plotted as a function of transition type (DD or RR, DI or RG, II or GG, and ID or GR) for each FR. Note that running-response rates cannot be calculated for the FR 1 conditions.

panel) were higher than those in the 8-s and 32-s conditions for all transitions ($F(2,40) = 23.17$, $p < .05$); however, in the FR-40 condition, the addition of delay tended to lower response rates ($F(2,24) = 4.28$, $p < .05$). Running-response rates did not decrease consistently with increases in delay from 8 to 32 s for any transition type. Figure 6 shows that the variation between hens' response rates tended to decrease with increases in FR value. Running-response rates for each hen also decreased in variability with increases in FR value but did not vary systematically with changes in transition type or delay (Appendices 3 and 4).

Delay to Reinforcement and Within-Delay Responses

The onset of the delay to reinforcement was signaled by the offset of the key light. Responses to the darkened key were recorded allowing calculation of the delay between the last response and the reinforcer. Experienced and programmed delays differed by more than 1 s on only five occasions (median = 1.99 s), all for delays of 32 s. The largest difference was for Hen 64 whose obtained delay in the 32-s delay condition was only 9.53 s. This occurred because this hen pecked the dark key an average of 2.59 times during the delay. No other hen pecked more than once during this delay and these tended to occur at the start of a delay.

DISCUSSION

The present experiment investigated the effects of adding a signaled, nonresetting delay to one component of multiple FR FR schedules on between-ratio pauses. Pause duration was longer when the upcoming reinforcer was to be delayed than when it was not to be delayed. This finding provides further evidence that pausing in FR schedules is a function of signaled upcoming events. Pauses tended to be longer at transitions from Immediate to Delay components when compared with pauses in the Delay components that followed Delay components. Therefore, the preceding component also influenced the pause, although the effect was much weaker than the effect of the current component. Thus, if the length of the pause reflected the 'favorableness' of the conditions signaled in that component, as suggested by Wade-Galuska *et al.* (2005), Delay components were made more unfavorable when the preceding experience was an immediate reinforcer than when it was a delayed reinforcer. There was also a tendency for pauses in an Immediate component that followed an Immediate component to be shorter than those in Immediate components that followed Delay components, but these differences were not significant. Other research using multiple FR FR schedules (Baron & Herpolsheimer, 1999; Griffiths & Thompson, 1973; Mintz *et al.*, 1967; Perone & Courtney, 1992, Wade-Galuska *et al.*, 2005) has also found pause duration both to be most influenced by the conditions in the current

component and to be influenced, to some extent, by conditions in the preceding component.

As previously reported, the manipulation of ratio size, reinforcement magnitude, and the force requirement all influence between-ratio pause durations in multiple FR FR schedules (Baron & Herpolsheimer, 1999; Crossman, 1968; Griffiths & Thompson, 1973; Inman & Cheney, 1974; Mintz *et al.*, 1967; Perone & Courtney, 1992; and Wade-Galuska *et al.*, 2005). In these studies durations of between-ratio pausing increased when the upcoming reinforcer was of lesser magnitude, required greater force, or was delayed due to an increased FR size. The present findings add delay to reinforcement as another parameter which affects pause duration in multiple FR FR schedules.

Comparisons from Immediate and Delay components show that both changes in response requirement and changes in delay increased pause durations. Increasing delay decreases the rate of reinforcement and, if it is assumed that responses occur at a steady rate, increasing response requirement also decreases rate of reinforcement. Thus both manipulations reduced reinforcement rate. For the present data, estimates of reinforcement rate based on the median running-response rates showed that increasing the response requirement from 15 to 40 decreased the obtained rate of reinforcement more than did changing the delay from 8 to 32 s. Thus the FR changes had the larger effect on this measure.

The procedure used in the present study did not allow the effects of changes in delay and changes in response requirement on rate of reinforcement to be evaluated separately. It could be that the reinforcement rate changes resulting from the response requirement and delay manipulations were the main contributor to the changes in pause duration. However, Wade-Galuska *et al.* (2005) have shown that changes in effort, and Inman and Cheney (1974) and Perone and Courtney (1992) have shown that changes in reinforcer magnitude both have similar effects on pause length to those found here with delay, and changing reinforcer magnitude and response effort do not necessarily alter the rate of reinforcement. It might be that these parameters have their effects through altering the 'value' of the reinforcement. Such a suggestion could be

examined further using other parameters known to affect the value of reinforcement. For example, varying the quality of the reinforcer has been found to influence behavior under single FR schedules (e.g., Foster, Sumpter, Temple, Flevill & Poling, 2009). Thus, the present research could be extended by using reinforcers of differing quality rather than delay. If it was the value of the reinforcement that was important here, then pausing should be longer in the component prior to an FR schedule delivering a lower quality of food, and, if the present findings were replicated, pausing should be longer in these components when the preceding component delivered the higher quality of food. It would also be of interest to examine the effects of the addition of a potentially aversive stimulus, such as a loud white noise, during one component.

Staddon and Cerutti (2003) suggested that ideas derived from pausing on interval schedules may be directly applicable to FR schedules. They point out that research on fixed-interval (FI) schedules suggests that the length of the waiting period or pause prior to the first peck after a reinforcer on these schedules is related to the length of the previous interfood interval (IFI). In particular the research shows that there is a linear relation between the pause or wait time in the current interval and duration of the previous IFI. This wait time is thought to be obligatory, and such pauses occur even under response-initiated FI schedules where they reduce the reinforcement rate. Under cyclic FI schedules, when the changes in interval length are orderly, this pause tracks changes in interval length. Innis, Mitchell, and Staddon (1993), using response-initiated delay schedules with pigeons, showed that the just-experienced IFI influenced pause duration rather than the upcoming one, and they also found that earlier intervals might also have some influence. This was not the effect seen under the present procedure with FR schedules. In the present study it was the upcoming IFI that had the greatest effect on pause duration, and the effect of a preceding short IFI (an Immediate component) was to increase pause length in the following Delay component rather than decrease it.

Church and Lacourse (1998), using interval schedules, found that rats would learn to track a regular series of 12 intervals and that pause

duration was influenced by the upcoming IFIs. They point out that their rats could anticipate the length of the upcoming IFIs and that pause duration was not related to the upcoming IFI when the intervals were randomly presented. Their results are similar to the present findings and together they suggest that it may be the provision of stimuli that signaled the upcoming conditions that was important in the present procedure. A replication using FI schedules would help to clarify whether it was the type of schedule or the provision of stimuli that gave rise to the present findings. It could be that such signals are necessary for upcoming conditions to influence "present" pause durations.

One possible confound with the present procedure was that the key was still present during the delay to reinforcement and so the hen could still respond. Thus, it was possible that the delays between the last response prior to reinforcer delivery and the reinforcer delivery were not as intended. However, very few responses were made during the delays and those that were made occurred early in the delays for all but one condition for one hen. Examination of the experienced delays and the timing of these dark-key responses showed that most of these responses occurred reasonably simultaneously with the offset of the keylight. This suggests that the responses were the result of the hen not stopping responding immediately after the key light extinguished and sometimes making one or two more responses than required. However, given that the experienced delays were close to those programmed, it is argued that the occurrence of these dark-key responses did not affect the conclusions drawn. It should be noted that one aspect of the procedure that might have discouraged responses to a dark key was that the hens experienced the key being inoperative and dark both prior to and at the end of each session. This regular experience of inoperative dark keys might have made it more likely the hen would learn to stop responding on darkened keys.

Running-response rates were examined and it was found that that they tended to decrease as FR size increased. The effects of delay on these response rates were not as consistent. The rates were affected by the presence of a delay to reinforcement in that they were slower in Delay components than in Immediate

components, a finding similar to that Wade-Galuska *et al.* (2005) with force. However, the effects of increasing delay were not consistent. Perone and Courtney (1992) also found the effects of reinforcer magnitude on running-response rates were not consistent across subjects. Other multiple FR FR studies do not report these rates. It appears that changing the outcome changes more consistently pause duration than running response rate under multiple FR FR schedules.

The present study used multiple FR FR schedules and of interest is how the data compare to data from single FR schedules. Foster, Blackman, and Temple (1997) report data from single FR schedules with hens and the pause durations are very similar to those from the 0-s delay conditions here. As previously reported, both response requirement and delay have been studied under single FR schedules. Pause durations increase with increases in response requirement under such schedules (Powell, 1968), as was seen for both Immediate and Delay components here. Increasing delay to reinforcement also increases pause duration under single FR schedules (Morgan, 1972; Topping, Johnson & McGlynn, 1973) and such increases were seen in the Delay components here. Thus, the changes in pause durations here were at least qualitatively similar to those reported for single FR schedules. How these changes compare in magnitude to those seen in single FR schedules remains to be investigated.

The findings from single FR schedules concerning the effects of changes in delay to reinforcement on running-response rates are mixed. Azzi, Fix, Keller and Rocha e Silva (1964) found that increasing delay to reinforcement reduced running-response rate, while others have reported no effect of delay (Morgan, 1972; Topping *et al.*, 1973). These findings, together with those from the present experiment, suggest that the between-ratio pause duration might be a useful measure for assessing the effects of varying the parameters of the reinforcer (e.g., quality, magnitude, or delay) on FR schedule performance. This might be more consistent than the overall response rate which is presently the most frequently used measure (e.g., Foster *et al.*, 2009; Hursh & Silberberg, 2008).

In sum, the present experiment found that a) adding a signaled, nonresetting delay to

reinforcement in one component of multiple FR FR schedules increased between-ratio pauses in Delay components but not in Immediate components; b) median pause durations in Delay components increased with the length of the delay and with the response requirement; c) as median pause durations increased, pauses became more variable, a result consistent with Weber's law for time; d) there was an effect of the preceding schedule on pause duration, in particular Delay components had longer pause durations when preceded by Immediate components, suggesting that although the conditions arranged in upcoming components had the larger effect, those in the preceding components also influenced pause length and so the term 'between-ratio pauses' may be a better descriptor of these pauses than 'post-reinforcement pause'; and e) that running-response rates did not change systematically with delay size, thus changes in the between-ratio pause durations might better reflect changes in the value of reinforcement in a component than do changes in response rates.

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APPENDIX 1

The medians and the interquartile ranges of the pause durations for the last ten sessions of each of the FR 5 conditions.

		Transition Type							
Hen	Delay (s)	Median				Interquartile Range			
		DD	DI	II	ID	DD	DI	II	ID
61	0	3.07	3.05	2.45	2.70	0.75	0.86	0.35	0.64
	4	4.70	2.10	2.85	5.72	1.16	0.76	0.45	0.81
	8	5.35	3.52	2.90	9.45	5.30	4.53	2.38	9.40
	16	12.42	1.40	1.70	10.85	5.65	0.58	0.68	8.04
	32	15.05	1.80	1.63	14.85	6.34	0.58	0.69	3.23
62	0	1.72	1.90	1.80	1.80	0.35	0.44	0.55	0.33
	4	2.90	2.05	2.20	2.92	0.63	0.65	0.84	1.11
	8	5.20	2.35	3.00	7.35	1.74	0.55	3.26	1.65
	16	8.03	2.60	2.88	11.25	3.15	0.43	0.93	3.86
	32	19.43	4.33	5.05	22.40	11.34	0.89	1.41	2.63
63	0	2.95	2.48	2.83	3.40	1.56	0.75	0.89	1.24
	4	2.30	1.60	1.68	2.20	0.65	0.41	0.44	3.45
	8	6.45	1.88	1.88	9.30	3.63	0.50	0.79	3.24
	16	7.85	2.20	3.50	8.38	4.01	0.55	1.69	1.14
	32	13.30	3.63	4.70	19.50	7.33	0.86	0.90	7.35
64	0	1.80	1.68	1.80	1.93	0.38	0.14	0.25	0.50
	4	3.95	1.88	1.75	4.60	2.49	0.70	0.71	1.75
	8	6.75	3.00	2.90	7.88	2.94	0.71	0.25	8.66
	16	8.48	2.55	2.60	10.35	7.75	1.04	0.48	4.69
	32	15.68	2.60	2.75	21.78	7.45	0.38	0.44	13.64
65	0	2.78	2.73	2.85	3.05	0.63	0.50	0.25	0.35
	4	8.40	3.15	6.18	8.65	3.40	2.06	5.21	2.83
	8	10.15	2.70	3.58	12.60	2.95	0.41	2.40	2.85
	16	19.60	5.08	5.40	18.40	14.83	1.89	1.89	4.73
	32	17.98	2.83	4.03	20.93	7.29	0.51	1.33	5.71
66	0	2.40	2.35	2.15	2.43	0.40	0.55	0.28	0.40
	4	3.50	2.75	2.63	3.43	1.14	0.66	0.85	0.50
	8	5.20	3.40	2.93	5.15	2.14	1.10	1.01	2.30
	16	11.10	3.50	3.53	14.53	10.03	0.33	0.33	9.79
	32	13.90	3.88	4.15	15.90	6.56	0.50	0.74	9.74

APPENDIX 2

The medians and the interquartile ranges of the pause durations for the last ten sessions of the FR 1, FR 15, and FR 40 conditions.

		Transition Type							
		Median				Interquartile Range			
Hen	Delay (s)	DD	DI	II	ID	DD	DI	II	ID
FR 1									
61	0	0.70	0.63	0.70	0.65	0.34	0.45	0.31	0.19
	8	3.77	0.97	0.90	4.72	0.90	0.09	0.49	1.08
	32	8.70	0.95	1.00	9.12	0.28	3.55	2.88	0.25
62	0	1.67	1.62	1.95	1.28	0.68	0.58	0.68	0.25
	8	2.40	0.60	0.40	3.00	0.91	0.08	0.09	0.81
	32	11.27	1.60	1.15	16.40	0.45	5.28	3.79	0.59
63	0	1.65	1.95	2.02	1.65	0.15	0.26	0.45	0.26
	8	5.70	1.95	2.33	7.55	2.25	0.65	0.83	1.68
	32	18.62	2.60	3.35	23.47	0.63	16.43	6.04	0.76
64	0	1.60	1.72	1.82	1.72	0.83	0.53	0.79	0.43
	8	4.10	1.77	2.27	5.42	1.53	0.51	0.98	2.50
	32	10.30	2.47	3.25	23.57	3.03	4.76	6.38	1.00
65	0	2.05	2.00	1.97	2.08	0.75	0.65	0.34	0.55
	8	10.95	1.97	2.10	15.00	5.24	0.39	0.49	4.85

APPENDIX 2

(Continued)

Hen	Delay (s)	Transition Type							
		Median				Interquartile Range			
		DD	DI	II	ID	DD	DI	II	ID
FR 15	32	6.60	2.32	2.35	10.22	2.80	3.36	4.98	0.94
61	0	2.92	3.00	3.25	2.75	0.74	0.39	0.88	0.63
	8	7.87	3.00	2.70	9.85	4.19	0.66	0.46	3.59
62	32	17.50	1.95	2.30	19.77	5.16	0.28	0.61	4.55
	0	2.25	3.38	2.75	2.50	0.98	0.85	1.73	1.28
63	8	11.15	4.87	5.15	18.35	2.63	1.15	1.98	3.13
	32	4.87	4.35	4.60	36.55	0.96	0.73	1.21	6.99
64	0	8.05	7.42	7.45	9.02	2.78	0.76	0.70	2.56
	8	14.55	7.82	10.12	31.97	6.29	0.80	3.26	7.86
65	32	29.15	7.85	12.05	38.75	11.23	2.96	4.40	18.91
	0	3.80	3.95	3.65	4.75	0.98	1.54	1.78	4.19
66	8	16.35	6.27	7.75	26.85	3.70	4.90	6.35	11.20
	32	15.82	7.32	4.35	28.85	12.46	4.61	1.39	10.24
67	0	7.35	8.50	7.40	7.72	1.08	2.55	1.38	1.63
	8	16.10	8.95	8.27	25.95	11.59	2.06	2.26	7.30
68	32	30.40	7.75	8.00	31.37	17.56	1.80	2.16	14.18
	0	4.30	7.27	4.60	4.20	0.80	2.26	1.18	0.64
69	8	9.45	4.25	3.85	13.05	3.93	1.34	0.79	5.43
	32	19.77	3.95	3.85	30.47	9.60	0.74	0.55	7.20
FR 40									
61	0	6.95	14.70	6.90	7.75	1.43	5.66	2.34	1.75
	8	8.07	5.75	4.25	12.40	1.13	1.45	0.59	1.23
62	32	16.95	3.75	3.10	29.95	9.58	0.63	0.68	3.76
	0	8.35	10.92	7.95	9.85	1.04	1.75	2.13	1.16
63	8	12.37	7.22	7.65	29.00	6.40	0.99	2.33	11.54
	32	25.17	3.77	6.15	50.75	9.15	0.68	2.28	13.93
64	0	14.62	18.92	16.22	33.77	6.19	6.15	3.65	16.70
	8	11.55	12.70	8.60	30.65	3.13	5.51	3.08	8.88
65	32	18.95	19.60	11.55	21.32	8.28	7.64	3.70	5.44
	0	55.22	13.05	10.45	68.20	39.01	3.93	5.94	20.44
66	8	14.20	13.22	14.77	17.65	5.05	3.31	7.45	3.23
	32	30.08	24.60	13.63	25.00	8.99	3.11	3.70	9.16
67	0	34.35	10.40	7.12	38.27	10.84	3.01	2.00	10.96
	8	8.55	14.85	6.82	10.55	3.55	5.25	2.88	3.00
68	32	14.42	10.35	4.92	12.67	5.46	3.50	1.84	5.70

APPENDIX 3

The medians and the interquartile ranges of the running-response rate (per s) for the last ten sessions of the FR 5 conditions.

Hen	Delay (s)	Transition Type							
		Median				Interquartile Range			
		DD	DI	II	ID	DD	DI	II	ID
61	0	2.44	3.33	3.33	2.47	0.58	0.69	0.44	0.24
	4	2.25	2.02	2.17	2.13	0.83	0.33	0.66	1.10
	8	2.00	2.12	2.34	1.39	0.62	0.96	1.19	1.36
	16	1.30	2.22	2.22	1.12	0.21	0.56	0.31	0.21
	32	1.12	2.38	2.22	1.15	0.55	0.86	0.32	0.52
62	0	2.33	1.40	1.40	2.56	0.63	0.73	1.03	0.24
	4	0.98	2.50	2.83	0.58	0.90	0.85	0.76	1.13
	8	1.29	2.17	2.39	0.80	1.11	1.24	0.80	1.37
	16	2.30	1.28	1.24	1.74	1.42	0.68	0.39	1.30
	32	1.16	0.93	0.87	1.14	0.27	0.24	0.23	0.68
63	0	1.75	1.77	2.00	1.82	0.59	0.75	0.86	0.80

APPENDIX 3
(Continued)

		Transition Type							
Hen	Delay (s)	Median				Interquartile Range			
		DD	DI	II	ID	DD	DI	II	ID
64	4	1.08	1.88	2.06	1.15	0.39	0.50	1.23	1.23
	8	0.61	2.08	1.88	0.35	1.15	0.43	0.56	0.33
	16	1.94	2.47	2.10	1.52	0.54	0.78	0.49	0.50
	32	1.04	1.61	1.08	0.67	0.95	0.65	0.57	0.54
	0	2.64	2.99	3.04	2.61	0.90	0.62	0.46	1.03
	4	1.19	2.82	3.04	0.92	0.91	0.77	1.04	0.43
	8	1.08	2.78	2.82	0.79	0.59	0.56	0.98	0.24
	16	1.07	2.67	2.44	0.94	1.18	0.61	0.52	0.35
65	32	1.35	2.27	2.44	1.39	0.83	0.45	0.85	0.58
	0	2.42	2.57	2.75	2.29	0.91	1.09	1.08	1.06
	4	1.32	1.86	2.06	1.19	0.80	0.63	0.92	0.50
	8	1.20	1.79	1.75	0.90	0.67	0.62	0.59	0.46
	16	1.25	1.92	1.81	0.96	1.20	0.33	0.49	0.30
	32	1.05	1.86	1.77	0.89	0.35	0.36	0.33	0.48
	0	2.86	2.78	2.78	2.94	0.36	0.29	0.12	0.32
	4	1.28	1.20	1.77	1.15	0.81	0.79	1.11	1.02
66	8	0.62	1.17	1.18	0.47	0.29	0.91	1.19	0.59
	16	1.06	1.94	1.70	0.85	0.52	0.80	0.76	0.29
	32	0.87	1.97	1.62	1.14	0.46	0.36	0.33	0.18

APPENDIX 4

The medians and the interquartile ranges of the running-response rate (per s) for the last ten sessions of the FR 15 and FR 40 conditions.

		Transition Type							
		Median				Interquartile Range			
Hen	Delay(s)	DD	DI	II	ID	DD	DI	II	ID
FR 15									
6	0	0.95	1.01	0.94	0.93	0.09	0.15	0.10	0.14
	8	0.75	0.89	0.84	0.55	0.12	0.10	0.17	0.14
	32	0.51	0.78	0.79	0.40	0.18	0.08	0.06	0.12
62	0	0.70	0.62	0.68	0.71	0.14	0.13	0.18	0.08
	8	0.57	0.51	0.51	0.44	0.23	0.05	0.08	0.13
	32	0.46	0.51	0.47	0.31	0.16	0.16	0.17	0.09
63	0	0.86	0.95	1.03	0.82	0.06	0.11	0.14	0.09
	8	0.21	0.72	0.72	0.15	0.09	0.12	0.27	0.05
	32	0.43	0.68	0.62	0.35	0.13	0.14	0.13	0.13
64	0	0.66	0.65	0.68	0.54	0.19	0.13	0.20	0.14
	8	0.15	0.32	0.29	0.12	0.04	0.09	0.14	0.03
	32	0.36	0.76	0.69	0.25	0.32	0.12	0.23	0.12
65	0	0.49	0.45	0.45	0.44	0.16	0.07	0.08	0.10
	8	0.32	0.50	0.55	0.29	0.09	0.11	0.14	0.05
	32	0.31	0.55	0.51	0.29	0.09	0.09	0.05	0.03
66	0	0.50	0.47	0.51	0.51	0.12	0.06	0.23	0.12
	8	0.43	0.46	0.57	0.33	0.16	0.27	0.27	0.16
	32	0.38	0.55	0.43	0.32	0.08	0.11	0.13	0.08
FR 40									
61	0	0.24	0.18	0.20	0.23	0.02	0.05	0.03	0.03
	8	0.29	0.29	0.30	0.25	0.04	0.04	0.03	0.05
	32	0.13	0.27	0.26	0.12	0.03	0.02	0.03	0.03
62	0	0.18	0.17	0.18	0.18	0.02	0.02	0.02	0.02
	8	0.18	0.27	0.27	0.14	0.06	0.01	0.03	0.03
	32	0.11	0.25	0.24	0.12	0.03	0.01	0.03	0.02

APPENDIX 4
(Continued)

Hen	Delay(s)	Transition Type							
		Median				Interquartile Range			
		DD	DI	II	ID	DD	DI	II	ID
63	0	0.10	0.10	0.10	0.08	0.02	0.03	0.01	0.02
64	0	0.10	0.10	0.11	0.08	0.03	0.03	0.02	0.02
	8	0.10	0.09	0.12	0.08	0.02	0.01	0.03	0.02
	32	0.07	0.20	0.20	0.07	0.01	0.06	0.03	0.00
65	0	0.14	0.17	0.18	0.15	0.02	0.02	0.03	0.04
	8	0.17	0.20	0.20	0.16	0.01	0.00	0.02	0.03
	32	0.10	0.19	0.19	0.09	0.02	0.03	0.03	0.01
66	0	0.14	0.14	0.14	0.14	0.02	0.10	0.07	0.04
	8	0.24	0.26	0.27	0.24	0.04	0.04	0.03	0.04