BRIEF COMMUNICATION

Timing in Pigeons: Effects of the Similarity Between Intertrial Interval and Gap in a Timing Signal

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Previous research suggests that when a fixed interval is interrupted (known as the gap procedure), pigeons tend to reset memory and start timing from 0 after the gap. However, because the ambient conditions of the gap typically have been the same as during the intertrial interval (ITI), ambiguity may have resulted. In the present experiment, the authors found that when ambient conditions during the gap were similar to the ITI, pigeons tended to reset memory, but when ambient conditions during the gap were different from the ITI, pigeons tended to stop timing, retain the duration of the stimulus in memory, and add to that time when the stimulus reappeared. Thus, when the gap was unambiguous, pigeons timed accurately.

The peak procedure, used to examine the ability of animals to time the duration of a stimulus (Catania, 1970), involves the use of a fixed interval (FI) schedule of reinforcement in which reinforcement is provided for the first response that occurs after the interval has elapsed. It is possible to use an animal’s response rate throughout the interval to assess its timing ability. Typically, an upwardly sloping response scallop is found (Church, 1978; Gibbon, 1977; S. Roberts & Church, 1978). Infrequent nonreinforced probe trials that are longer in duration than the FI trials are used to assess the response rate following the time that reinforcement would have occurred. On probe trials, there is generally an upwardly sloping response-rate function that peaks at about the time that reinforcement is provided for the first response that occurs after the interval has elapsed. It is possible to use an animal’s response rate throughout the interval to assess its timing ability. Typically, an upwardly sloping response scallop is found (Church, 1978; Gibbon, 1977; S. Roberts & Church, 1978). Infrequent nonreinforced probe trials that are longer in duration than the FI trials are used to assess the response rate following the time that reinforcement would have occurred. On probe trials, there is generally an upwardly sloping response-rate function that peaks at about the time that reinforcement would normally occur and then slopes downward to a level of low responding.

One question researchers have asked is what happens when a to-be-timed stimulus is interrupted during a timing episode. A stimulus can be presented, turned off for some time, and then presented again. Under these conditions, animals could (a) time through the interruption or break, (b) reset memory and start timing from zero when the stimulus is turned back on, or (c) maintain the initial time of the stimulus in memory and add to that time when the stimulus is turned back on. The break procedure was developed to ask how animals time under these conditions.

Fixed Interval Timing With Break Periods

S. Roberts (1981) proposed that resetting memory during a break should result in a shift in peak responding to the right of nonbreak probe trial peak responding (i.e., a later peak) that should be equal to the total time that had elapsed prior to the break (the reset rule). Alternatively, if the animals stop timing during a break, but retain in working memory the time elapsed before the break, the animals should continue to add to the duration that was stored before the break (the stop–retain rule). A shift in peak responding to the right of nonbreak probe-trial responding also should result, but that shift should be equal to the duration of the break. Finally, if animals continue to time through the break, there should be no shift from nonbreak probe-trial peak responding.

Although the terminology used here (e.g., the reset rule and the stop–retain rule) is consistent with the analogy of an internal clock, the existence of such a clock is not assumed, nor is it necessary for the present argument. There are several theories of animal timing (i.e., the multiple-time-scale theory; Staddon & Higa, 1999), scalar expectancy theory (Gibbon, 1977) and the behavioral theory of timing (Killeen & Fetterman, 1988). The most popular of these, scalar expectancy theory, posits the operation of an internal clock (Church, 1984; Gibbon & Church, 1984; Gibbon, Church, & Meck, 1984). However, at least one theory rejects the notion of such a clock and attributes the timing ability of animals to the relative strength of memory traces over time (Staddon & Higa, 1999). For purposes of the present discussion, it is not necessary to differentiate among these theoretical positions. The terms used here are merely descriptive of proposed timing effects and do not imply a particular theoretical account.

S. Roberts (1981) tested rats with a 10-s break that began 15 s into a nonreinforced (empty) trial, a 5-s break that began 15 s into an empty trial, and a 5-s break that began 10 s into an empty trial. According to the reset rule, peak responding should be shifted 25, 20, and 15 s to the right of nonbreak probe-trial peak responding, respectively, for the three conditions. According to the stop–retain rule, peak responding should be shifted 10, 5, and 5 s to the right of nonbreak probe-trial peak responding, respectively, for the three conditions. S. Roberts found that regardless of when the break

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occurred during an empty trial, a 10-s break increased the time of peak responding by about 13 s, and a 5-s break increased time of peak responding by about 8 s. The increase in time of peak responding was proportional to the duration of the break, a result that supported the stop–retain rule, but in all conditions the shift in peak responding was about 3 s longer than the duration of the break. S. Roberts postulated that the 3-s lag in peak time occurred either because it took longer to restart timing than it did to stop timing or because the break partially reset memory. In either case, the results were clearly more consistent with the stop–retain rule than with the reset rule.

W. A. Roberts, Cheng, and Cohen (1989) conducted an experiment similar to that of S. Roberts (1981) but with pigeons. Although their procedure was somewhat more complex, the logic was the same. W. A. Roberts et al. trained pigeons on two FI schedules at the same time. The birds were trained with a light signal that resulted in reinforcement on an FI 30-s schedule and at the same time they were trained with a tone signal that resulted in reinforcement on an FI 15-s schedule. Following acquisition, 90-s nonreinforced probe trials were inserted on trials with each signal type. On probe trials, W. A. Roberts et al. found that pigeons demonstrated clear peaks at the appropriate time for each signal type. They then introduced break trials on light- and tone-signalized trials. They used break durations of 1, 3, and 9 s, which always began 9 s into a 90-s nonreinforced trial and found that for all break durations, the peak shift that resulted favored the reset rule. However, the clearest support was obtained for 9- and 3-s breaks. When the break was 1 s, the peak shift fell between the values predicted by the two rules.

Cabeza de Vaca, Brown, and Hemmes (1994) entertained an alternative hypothesis to explain how animals time during a break. They noted that S. Roberts (1981) and W. A. Roberts et al. (1989) had formed opposite conclusions about how animals time during a break trial. In both cases, however, there was evidence that the animals performed at a level somewhat between the reset and stop–retain rules. Cabeza de Vaca et al. proposed, what might be referred to as, the stop–retain–decay hypothesis to account for these findings. According to their hypothesis, animals stop timing when a break occurs and maintain in working memory the time that had elapsed before the break. During the break, however, the duration stored in memory experiences some loss perhaps because of subjective shortening (e.g., Spetch & Wilkie, 1983). Following the break, when the signal is turned back on, the animals begin adding to the subjectively shortened duration. This process should result in a shift in peak responding that is greater than what is predicted by the stop–retain hypothesis but less than what is predicted by the reset rule. An additional prediction of this hypothesis is that the longer the break duration, the more the shift in peak responding should approximate predictions based on the reset rule (i.e., because memory for the prebreak period should get progressively shorter).

Cabeza de Vaca et al. (1994) trained pigeons on an FI 30-s schedule with intermittent 90-s probe trials. Following training, pigeons were tested with three types of break conditions. An early-onset short break that began 6 s into the trial and lasted for 6 s, a late-onset short break that began 15 s into the trial and lasted for 6 s, and an early-onset long break that began 6 s into the trial and lasted for 15 s. Cabeza de Vaca et al. found that in all three conditions the shift in pigeons’ peak responding fell somewhere in between what would be predicted by the reset and stop–retain rules, however, what was most convincing was that with long duration breaks, the pigeons’ peak shifts were more congruent with the peak shift predicted by the reset rule. Their findings support the stop–retain–decay hypothesis. In fact, as was noted earlier, the findings of W. A. Roberts et al. (1989) are also consistent with the stop–retain–decay hypothesis, because longer break durations resulted in shifts in peak responding that were more like reset than were shorter break durations.

This finding was replicated by Buhusi and Meck (2000) using breaks of 1, 5, and 15 s. Interestingly, however, Buhusi and Meck included a second condition in which rats were trained to time the duration of the absence of a signal (the reverse gap procedure). The first response 30 s after the offset of a signal (white noise or houselight) resulted in reinforcement and terminated the trial. Under these conditions, even brief gaps (which were now signaled by the presence of a stimulus) produced peak shifts that were more consistent with the reset rule (except the 1-s stimulus that produced shifts that fell between predictions of the reset and stop–retain rules). This finding indicates that the nature of the to-be-timed stimulus (perhaps its saliency relative to other within trial events) can have dramatic effects on how animals respond to a break in a timing episode.

The Instructional Ambiguity Hypothesis

Although Cabeza de Vaca et al.’s (1994) hypothesis is supported by the results of their experiment, there is an alternative explanation for their findings. In their experiment (as well as experiments by S. Roberts, 1981; W. A. Roberts et al., 1989; and Buhusi & Meck, 2000), the ambient conditions in the operant chamber were the same during the breaks and the intertrial intervals (ITIs). For the pigeons, the fact that the breaks may have been indistinguishable from the ITIs could have encouraged them to treat the breaks as if they were an ITI. If it is assumed that the pigeons use the ITI to clear out the memory trace from the preceding trial (so it doesn’t affect performance on the succeeding trial), one would expect them to reset and start timing anew at the end of the break (as they typically do following the ITI). Thus, resetting memory during the break might be thought of as a “failure of instructions” (Zentall, 1997) due to the inadvertent similarity of the ITI and break. Furthermore, given that longer breaks are more similar to ITIs (in duration), pigeons should be more likely to reset memory following a long break than following a shorter break. The instructional ambiguity hypothesis provides a metaphor to distinguish between internal timing and memory effects and inadvertent methodological artifacts.

The purpose of the present research was to test the instructional ambiguity hypothesis by manipulating whether the ambient conditions during the ITI and break were similar or different (for a similar manipulation used in a match-to-sample design, see Shershube, Zentall, & Kaiser, 1998). In the present research, pigeons were trained on the variation of the peak procedure used by Cabeza de Vaca et al. (1994). Half of the pigeons were trained with a dark ITI and the other half were trained with a lit ITI. The timing stimulus was a white key light. On reinforced trials, responses to the white response key were reinforced on a FI 30-s schedule. On nonreinforced or baseline trials, the response key remained on for 90 s and reinforcement did not occur. Following training adequate
to produce a stable peak in responding, all pigeons received break trials similar in duration and temporal location in the trial to that used by Cabeza de Vaca et al. However, half of the break periods were lit, and the remainder were dark. If findings of earlier research were influenced by instructional ambiguity, then when the break houselight condition does not match that of the ITI, pigeons should show a peak shift that is indicative of timing in the absence of ambiguity. It was predicted either that these functions might be more consistent with the stop–retain rule, or if pigeons do not confuse the break with the ITI, they may continue to time throughout the break and thus, they may not show any shift in peak responding.

Method

Subjects

Twelve adult White Carneaux pigeons that had previous experience pecking lit response keys for food reinforcement were maintained at 80–85% of their free-feeding weights in individual cages. They had free access to water and grit and experienced a 12-hr light–dark cycle.

Apparatus

Two similar operant chambers (BRS/LVE, Beltsville, MD) were used for experimental sessions. The first chamber was 31.5 cm high, 35.5 cm side to side, and 32.0 cm from the response panel to the back wall. Three round response keys (2.5 cm in diameter), separated from each other by 6.0 cm, were centered on the response panel 20.0 cm from the wire mesh floor. Behind each response key was an in-line projector (Industrial Electronics Engineering, Series 10, Van Nuys, CA, with No. 1820 G.E. lamps). Only the center response key was used for these experiments. The center projector could project a white field on the center key. Reinforcement was provided through an illuminated 5.0 × 6.0-cm aperture centered on the response panel. The bottom edge of the aperture was 6.0 cm from the floor. General chamber illumination was provided by a shielded houselight that was centered on the response panel, 6.0 cm above the center response key. An exhaust fan and white noise masked extraneous sounds.

The second chamber, similar to the first, was 35.0 cm high, 35.0 cm side to side, and 31.0 cm from the response panel to the back wall. The second chamber had a tricolor lamp behind the center response key that could project white light by means of a 0.04 ampere lamp.

The events in both chambers were controlled by an IBM-compatible microcomputer located in an adjacent room. The events were programmed using MED Associates (St. Albans, VT) software and interface.

Procedure

Pretraining. The pigeons were initially placed on an autoshaping procedure to expedite the initial training procedure. The white key was lit for 6 s, after which it was extinguished, and the pigeons received 3 s of reinforcement (Purina Pro Grains). Following reinforcement, there was a variable-duration ITI with a mean of 45 s. For 6 of the pigeons, the houselight was lit during the ITI, and for the other 6, it remained dark. The pigeons received 24 trials per session with this autoshaping procedure during which pecks to the center key were recorded. Once pigeons pecked the center key regularly, they began training on the peak-procedure timing task.

Peak procedure. The pigeons initially experienced two types of trials. During each session, there were 36 FI 30-s trials. The center key was lit white, and the first response following the 30-s interval darkened the center key and provided 1.5-s access to mixed grain. The remaining 12 trials in each session were nonreinforced probe trials. On these probe trials, the center key remained lit for 90 s and was then darkened without reinforcement. For half of the pigeons, the houselight was lit during the variable-duration ITI (M = 45 s), and for the remaining pigeons, the houselight was not lit during the ITI (as during pretraining). The houselight was never lit while the center key was lit for either group. For all pigeons, each session began with a FI 30-s warm-up trial that was not counted as part of the 48-trial session. This warm-up trial was followed by a 15-s ITI. The remaining trials occurred randomly in blocks of four (i.e., 3 FI 30-s trials and 1 probe trial). The pigeons were trained for 40 sessions with this peak procedure.

After 40 sessions of training, the pigeons’ “time of peak responding” (peak time) was calculated. This calculation was similar to a method used by S. Roberts (1981) and the same as that used by Cabeza de Vaca et al. (1994). The procedure for calculating the peak time was as follows: The median time (time at which half of the responses had occurred over the twelve 90-s probe trials in each session) was calculated. If this median was less than 45 s, a new median was calculated that encompassed the range of zero to twice the initial median. If the initial median was greater than 45 s, a new median was calculated over a new range that had 90 s as the upper limit and twice the difference between the initial median and 45 s as the lower limit. This process was repeated until a median was found that was within 0.5 s of the previously calculated median. This final median was defined as the peak time (see S. Roberts, 1981). Following 40 sessions of training, if the peak times during each of the last five sessions of training fell within a range of 5 s, the pigeons were exposed to the testing procedure. Otherwise, the pigeons continued on original training until this criterion was met.

Break trials. Following criterion performance in acquisition, the pigeons were tested with six kinds of break trial: (a) There were early–short–dark break trials during which the key was darkened after it had been lit for 6 s and it remained dark for 6 s. Following the 6-s break, the key was relit and it remained lit for 78 s. (b) There were late–short–dark break trials during which the key was darkened after it had been lit for 15 s and it remained dark for 6 s. Following the 6-s break, the key was relit and it remained lit for 69 s. (c) There were early–long–dark break trials during which the key was darkened after it had been lit for 6 s and it remained dark for 15 s. Following the 15-s break, the key was relit and it remained lit for 69 s. The other three break trial types were similar to the first three, but the houselight was lit during the break; early–short–lit, late–short–lit, and early–long–lit break trials. The duration of all break trials was 90 s, and they all ended in nonreinforcement. In each 44-trial test session, there were 36 FI 30-s trials, 4 probe trials, and 4 of each kind of break trial. All trials occurred randomly in four 16-trial blocks. Peak times were calculated for each trial type (except the FI 30-s trials). In addition, a peak shift was calculated for each break type. The peak shift was calculated by subtracting the peak time for probe trials on a given session, from the peak time for each kind of break trial on that session. As in original training, each session started with a 30-s warm-up trial (followed by a 15-s ITI) that was not included in analyses. Data were collected from four test sessions, thus each data point for each pigeon consisted of 16 trials. Experimental sessions were conducted 6 days a week. In all analyses, the .05 level of statistical significance was adopted.

Results

Training

Pigeons trained with a lit ITI acquired the task in an average of 61.5 sessions. Pigeons trained with a dark ITI acquired the task in an average of 71.2 sessions. This difference was not statistically significant, F(1, 10) = 0.40.

Testing

The initial question was whether peak shifts differed when the ambient light conditions were the same during the break and the ITI as compared with when they were different. Over all break
types, there was a greater peak shift when ambient conditions
during a break matched the ITI than when ambient conditions
during a break did not match the ITI (see Figures 1 and 2). This
observation was confirmed by statistical analysis. A 2 (houselight
condition during ITI) × 2 (ITI–break similarity) × 3 (break type)
mixed group analysis of variance was conducted to compare the
peak shift on break trials that shared ambient conditions with the
ITI (same-break trials) with the peak shift on break trials that did
not share ambient conditions with the ITI (different-break trials).
There was no main effect of houselight condition, and it did not
interact significantly with any of the other variables, so the data
were collapsed across that condition, and a 2 (ITI–break similarity) × 3 (break type) analysis was adopted. This analysis revealed
that peak shifts were greater on same-break trials than on different-
break trials, as demonstrated by a significant main effect of ITI–
break-type similarity, \( F(1, 11) = 33.41 \).

Examination of Figures 1 and 2 indicates that the total peak shift
differed as a function of break type. The peak shift was smallest for
the early–short breaks, larger for the late–short breaks, and largest
for the early–long breaks. This observation was supported by a
significant main effect of break type, \( F(2, 22) = 78.56 \). In addition,
the difference between same-break trials and different-break trials
was similar across the three break types, thus the ITI–Break-Type
Similarity × Break Type interaction was not found to be signifi-
cant, \( F(2, 22) = 0.35 \). Because break onset (early vs. late) and
break duration (short vs. long) were not independent, separate
analyses were conducted in which peak shift for the two break-
onset times were compared (while holding break duration con-
stant) and peak shift for the two break durations were compared
(while holding break onset constant).

When peak shifts (pooled over same and different trials) were
compared for early–short and late–short breaks, it was found that

\[ \text{Figure 1. Mean responses per second as a function of time from the start of a trial on probe trials (solid lines) compared with mean responses per second on break trials of each type (dotted lines).} \]
peak shifts on late–short break trials were significantly longer than peak shifts on early–short break trials, \( F(1, 11) = 39.36 \). When peak shifts (pooled over same and different trials) were compared for early–short to early–long breaks, it was found that peak shifts on early–long break trials were also significantly longer than peak shifts on early–short break trials, \( F(1, 11) = 142.55 \).

During testing, over all three break types, the peak shift on same-break trials was greater than that on different-break trials during test. Taken alone, this provides some evidence that pigeons’ performance may be disrupted by break trials that have the same ambient conditions as the ITI. However, the peak shifts presented in Figure 2 provide more direct evidence as well. In general, over the three breaks, obtained peak shifts on same-break trials are more similar to peak shifts predicted by the reset rule than by the stop–retain rule, whereas on different-break trials, obtained peak shifts are more similar to peak shifts predicted by the stop–retain rule than by the reset rule. Apparently, when pigeons are disrupted by breaks that are similar to the end-of-trial cue (the ITI), they are more likely to reset and start timing anew after the break. When the pigeons are disrupted by breaks that have nothing in common with end-of-trial cues, however, they appear to retain memory for time before the break and add to that time after the break (i.e., stop–retain).

The top dotted line in Figure 2 represents the peak shift predicted by a pure reset rule, whereas the bottom dotted line represents the peak shift predicted by a pure stop–retain rule. It is clear that at both the early–short and early–long breaks, the obtained peak shifts on same-break trials are very close to that predicted by the reset rule, and the obtained peak shifts on different-break trials are very close to that predicted by the stop–retain rule. At the late–short break, however, the obtained peak shift is somewhat less than that predicted by the reset rule on same-break trials and somewhat greater than that predicted by the stop–retain rule on different-break trials. To statistically analyze these observations, single group \( t \) tests were conducted to compare obtained peak shifts on same- and different-break trials with peak shifts predicted by the reset and the stop–retain rules over the three breaks.

Obtained peak shifts on early–same-break trials differed significantly from peak shifts predicted by the stop–retain rule, \( t(11) = 4.67 \), but not from those predicted by the reset rule, \( t(11) = -1.36 \). The opposite was true on early–different-break trials. Obtained peak shifts on early–same-break trials differed significantly from peak shifts predicted by the reset rule, \( t(11) = -5.90 \), but not from those predicted by the stop–retain rule, \( t(11) = -5.99 \). This same pattern of results occurred on long-break trials. Obtained peak shifts on long–same-break trials differed significantly from peak shifts predicted by the stop–retain rule, \( t(11) = 8.70 \), but not from those predicted by the reset rule, \( t(11) = -8.77 \).

As one might predict from examination of Figure 2, the obtained peak shifts on late–same trials were significantly different from performance predicted by both the reset and stop–retain rules, \( t(11) = 8.79 \) and \( -5.59 \), respectively. This was also true for late–different trials, \( t(11) = 2.23 \) and \( -8.90 \), respectively.

As can be seen in Figure 2, at early–short and early–long breaks, peak shifts on same-break trials were as predicted by the reset rule, whereas peak shifts on different-break trials were as predicted by the stop–retain rule. The peak shifts obtained on late-break trials were less in accordance with the peak shifts predicted by either rule, whether the breaks were similar to or different from the ITIs. Overall, however, when different break periods were used, not only were the peak shifts smaller but the pigeons appeared to stop timing during a break, remembered the time that had elapsed prior to the break, and incremented that time when the to-be-timed stimulus was reinstated.

Discussion

Previous research indicates that pigeons may have a tendency to clear memory when there is a break in a to-be-timed stimulus on probe trials following FI training. This finding may have been influenced by the fact that the conditions present during the break have been similar to those present during the ITI. The present results provide evidence that when the illumination conditions during a break are distinct from those during the ITI, pigeons generally retain in memory the time elapsed before the break period and add to that memory when the stimulus appears again.

The only cause for the differences in peak shifts that occurred between conditions in the present experiment was whether the houselight conditions during the ITI and break periods matched or not. It may seem surprising that such a subtle manipulation could produce such large effects, but such findings are not unique in the timing literature. For example, using a duration match-to-sample task, in which the duration of the sample indicates which comparison stimulus is correct, Sherburne et al. (1998) found that when the ambient light conditions during the ITI were made distinct from those during the retention interval, pigeons’ delayed matching performance improved. As in the case of the peak procedure, when the retention interval and the ITI conditions were similar, pigeons tended to reset or to lose information about the duration of the sample. Thus, when the ambient conditions (e.g., context) during a delay or break are distinct from those of the ITI, pigeon
timing may be far more accurate and flexible than has been documented in the literature.

**Why Are Late–Short-Break Position Peak Shifts Less in Line With Stop–Retain and Reset Rules?**

Although most of the data are consistent with the stop–retain hypothesis, those from the late–short condition are not. One thing that distinguishes the late condition from the early condition is the fact that in the late condition, just prior to the break, the pigeons were probably responding, whereas in the early condition, they were probably not. Even though the late break was similar to the ITI, given its short duration and the fact that there was probably responding just prior to it, late breaks may not have provided the same ambiguity as early breaks. That could account for the reduced peak shift for that condition.

On the other hand, this account does not explain the somewhat longer than expected peak shift in the different break condition when the break was late. According to the stop–retain hypothesis, the pigeons should have picked up where they left off, but they showed a somewhat greater peak shift than predicted by the stop–retain hypothesis. It may be, however, that the 6-s break during which the pigeons were not pecking may have made it difficult for the pigeons to resume pecking at the same rate that they were when the break began. Further research is needed to understand how animals time during late breaks. It is clear that the nature of the to-be-timed stimulus (see, e.g., Buhusi & Meck, 2000), the duration of the break, the similarity of the break to ITI conditions, and where the break falls in a timing episode all contribute to the effects observed here and elsewhere. Perhaps the relation between behavior prior to the break and the effect of the break may also prove to be an important variable in determining the effects of breaks on timing.

**Are Rats and Pigeons Differentially Affected by Similarity of Breaks to ITIs?**

As reported earlier, S. Roberts (1981) found that the peak shifts of rats produced by breaks on probe trials following FI training were more consistent with the stop–retain than with the reset rule. Although S. Roberts found that the peak shifts obtained were somewhat greater than that predicted by the stop–retain rule, they were clearly more like that predicted by the stop–retain rule than those predicted by the reset rule. This result occurred despite the fact that the ambient conditions in the operant chamber were the same for the ITI and the break periods, the same condition that appears to cause pigeons to adopt a reset rule in the present experiment. The reason for this species difference in results is unclear, but it may have to do with the saliency of the break period. Rats are less visual than pigeons and may be less influenced by the ambient similarity of ITIs and break periods (but see the reverse gap procedure; Buhusi & Meck, 2000). Perhaps rats use ITI versus break duration to resolve ambiguity. If so, one might predict that rats presented with break periods similar in duration to ITI duration would adopt the reset rule. This would be further indication of the generality of instructional ambiguity effects.

**Conclusion**

In general, the present findings indicate that pigeons have an accurate and flexible ability to time stimuli and that their memory for duration is also accurate. This is in contrast to much of the literature on animal timing. Findings from duration matching-to-sample studies have consistently shown that pigeons are grossly inaccurate (on long-sample trials) after a delay as short as 4 s (see, e.g., Spetch & Rusak, 1989; Spetch & Rusak, 1992; Spetch & Wilkie, 1983). However, the retention interval in these duration matching-to-sample studies was very similar to the end-of-trial cue (the ITI). As noted earlier, when the ITI is made distinct from the retention interval, pigeons show more accurate and less biased retention functions (Sherburne et al., 1998). Findings from FI timing studies that have introduced breaks during the to-be-timed interval also suggest that pigeons have difficulty with memory for duration. However, these studies as well generally use retention intervals or breaks that are similar to the ITIs and that confound end-of-trial cues with the retention interval. Similarly, in FI timing research of the kind studied here, when ambiguity between the ITI and breaks is removed, it appears that pigeons can accurately time the duration of stimuli.

**References**


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