ANALYSIS OF REINFORCEMENT DURATION SEQUENCE AND TEMPORAL TRACKING IN PIGEONS

by

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Analysis of Reinforcement Duration Sequence and Temporal Tracking in Pigeons

Temporal control of behavior has been referred to as a wide range of behaviors that are organized by the learned sensitivity to duration of a stimulus or time between successive events that can range from seconds to minutes (e.g., Richelle & Lejeune, 1980; Higa & Staddon, 1997; Buhusi & Meck, 2005). The ubiquitous nature of temporal control is evident in vertebrates and well as invertebrates. An example of temporal control outside the laboratory is seen in Gallistels' (1990) book, in which he describes a study suggesting that honeybee foraging behavior is sensitive to the timed availability of food. In that study, sucrose was available at a stand periodically (15:00 to 17:00). The honeybees were numbered so as to keep track of their reappearance to the dish of sucrose. Training days consisted of bees coming to the sucrose dish and being counted. As bees would leave and fly back to their hive, they would recruit other bees to come to the dish. On the testing days the dish was empty, and on these days, bees began to show up every now and again and the number of bees steadily picked up as time when sucrose was normally available drew close. Around thirty minutes before time of availability of sucrose (on preceding training days) frequency of arrival of bees reached a peak level. These results show that bees have the ability to time availability of food. Over the years, temporal control of behavior has been studied extensively in the laboratory, by exposing animals to periodic appetitive or aversive stimuli, and observing how behaviors such as key pecking in pigeons adapt to temporal regularity of stimulus-events.

Interval Timing in the Laboratory

Definitions & Methods

In the laboratory, a standard method for studying temporal control of behavior involves measuring behavior after extensive training, often involving hundreds of trials of exposure to a

single interval value (e.g., Schneider, 1969). One of the simplest procedures is the *fixed interval* (FI) schedule procedure. On a FI schedule, a reinforcer (e.g., access to grain for hungry pigeons) becomes available for the first response (e.g., key pecking) after a fixed period of time has elapsed since delivery of the preceding reinforcer. For example, a FI 60 s schedule procedure begins with a "free reinforcer"(e.g., grain presentation for a duration of 4 s) and the first response after 60 s has elapsed is reinforced. During the interval, the amount of time that has elapsed and when responses are emitted are recorded.

FI schedules produce a distinctive pattern of responding between successive reinforcers (called an interval). At the beginning of an interval, following reinforcement, animals produce *post-reinforcement pause* (PRP), which is measured as time between the start of an interval and first response. Following PRP there is either a gradual acceleration of responding (e.g., Ferster & Skinner, 1957) or an abrupt change from low to high rates of responding called a "break-and-run" pattern (Schneider, 1969) as the end of the interval nears. The entire process is called *interval timing.*

A variation of the FI schedule is the *peak procedure* (e.g., Catania, 1970). The Peak procedure is a discrete-trial version of a FI schedule in which there are two types of trials, trials that end with reinforcement according to FI requirement and probe trials that are usually two to three time longer than FI-trials but do not end with reinforcement. During both trials there is a stimulus present that is turned off at the onset of reinforcement (for the food trials) or after interval duration ceases (for probe trial). Catania (1970) used a peak procedure with a target interval duration of 10 s. During "training" trials, reinforcement was available after 10 s had elapsed since the start of a trial. An inter-trial interval of 60 s occurred between training and probe trials. Catania (1970) found that during probe trials, rates of responding started off low and then increased up to approximately 10 sec (when reinforcement was usually available), followed

by a gradual decrease. Rate of responding during a trial was highest at or near (peaked) time of which reinforcer would be if it were a food trial.

Characteristics of Interval Timing

Evidence that behavior is under temporal control of the time-to-reinforcement on these procedures includes changes in PRP, overall *response rate,* and *running rate* (RR). Generally, PRP is approximately ¼ to ½ the target-interval duration. That PRP depends on interval duration shows that behavior is sensitive to interval requirement (e.g., Lowe & Harzem, 1977; Richelle & Lejeune, 1980; Shull, 1970; Zeiler & Powell, 1994). For example, Innis (1981) presented pigeons with a series of intervals that increased and then deceased, within session, according to an arithmetic progression, ranging from 30 to 120 s. Innis reported that as interval increased in duration PRP increased, and when interval duration decreased PRP decreased. The pigeons were able to distinguish the changes of interval duration by matching or changing their response pattern, referred to as *tracking.*

Another measure of timing is rate of responding during an interval. Of importance is the pattern of responses in an interval. Response rate is usually low at the start of an interval followed by either a gradual acceleration in responding (called a "scallop") or an abrupt transition from low to high rates of responding called "break-and-run" pattern. Of particular importance is the point in an interval in which response rate changes from low to high, called *break point*. For example, Schneider (1969) exposed pigeons to FI schedules ranging from 16 to 512 s. He found that after reinforcer was delivered that there was little or no responding, followed by high rates of responding. Specifically, break point in an interval increased with increases of FI requirement and, generally, longer than PRP and was about two-thirds the interval duration

An additional measure, running rate (RR) is a common measure of timing behavior and consists of overall rate of responding in an interval, excluding the time of the first response (i.e., PRP duration). For instance Zeiler and Powell (1994) exposed pigeons to seven different interval durations ranging from 7.5 to 480 s. Zeiler and Powell found that as PRP was directly related to duration of the interval and RR was inversely related. That is, when inter duration increased RR decreased and PRP increased. The over all response rate and RR are not a good measure of timing in that it does not reflect what was used as a stimulus by which time is marked. Interestingly, there could be species differences when RR is used as a measure of temporal control. For instance Lowe and Harzem (1977) compared rats and pigeons and found differences in RR as a function of reinforcement duration for rats but not in pigeons. A possible explanation was that behavior is different, being that rats press levers and pigeons peck keys (i.e., different response systems).

Lastly, two important hallmarks of interval timing that represent the relationship between independent variables (e.g., changes in the FI requirement) and dependent measures (e.g., PRP, RR) are proportional timing and scalar timing. *Proportional timing* occurs when there is a direct (linear) relation between dependent measures of temporal control and the to-be-timed interval duration (e.g., Staddon, 2001). For example, break point in responding during an interval is proportional to FI requirement (e.g., Schneider, 1969). *Scalar timing* involves measures of variability and occurs when standard deviation of dependent measures is proportional to their mean (e.g., Gibbon, 1977). Graphically, scalar timing can be seen when the response rate pattern from peak a procedure, under two different interval requirements, superimpose when the x- and y-axes are normalized (e.g., Gibbon, 1981).

Factors that Affect Interval Timing: Reinforcer Duration

Several factors are involved in temporal control of behavior, ranging from possible species differences (e.g., Lejeune & Wearden, 1991), magnitude of reinforcer (e.g., Richelle & Lejeune, 1980), to drug effects (e.g., Meck 1996; Odum, 2002). A factor that has not been studied extensively is the effect of magnitude of reinforcement on temporal behavior. Reinforcer magnitude can be split into different types, including *quality*, *quantity*, and *reinforcer duration* (RD). An early study by Staddon (1970) illustrates basic reinforcer magnitude effect. Staddon used pigeons as subjects and exposed them to FI 60 s schedule of reinforcement. Within a session, the duration of reinforcement varied and was 1.3, 2.4, 3.5, 5.7, or 9.0 s. The different reinforcer durations were randomized in blocks of five, and each session contained a total of 40 intervals. Staddon found that as reinforcer duration increased PRP increased and RR decreased in the *following* interval. When comparing the first five days to the last five days, at each reinforcer duration, response rate, RR, and PRP means showed marginal differences in overall patterns. That is, absolute levels changed, but the pattern between dependent measures and reinforce duration was relatively similar across training. Specifically, during the last five days of training, response rate declined from a high of 64 responses per minute from the first five days to a low of 55 as reinforcer duration increased. Also PRP, for the last five days, increased in duration from a low of 16 seconds from the first five days to a high of around 28 seconds as reinforcer duration increased. RR decreased as reinforcer duration increased for the last five days, ranging from 85 responses per minute for the first five days to a low of 74 responses per minute. These findings are of interest because they indicate that animals are using not just interval duration for timing. Instead, temporal behavior is determined by reinforcer duration. Which was thought irrelevant because the offset of the reinforecer signals the beginning of an interval and the onset signals the end.

In addition to reinforcer duration, concentration and number also have systematic effects on PRP duration. Lowe, Davey, and Harzem (1974) tested rats and changed concentration of milk reinforcer (ranging from 10% to 70%) within session using FI schedules of reinforcement and look at the effects on PRP and RR. As in Staddon's study, different concentrations were randomized within a session. Lowe et al. found that as concentration increased, PRP increased in duration and RR decreased. In another study, Blomeley, Lowe, & Wearden (2004) used the same concentrations of condensed milk within a session, but varied FI duration by exposing rats to two FI schedules, provided on different levers and available one at a time. Although, most all of their data comes from the FI 30 s schedule, these data show a concentration effect on PRP and *run time* (i.e., time between the first and the last response). PRP increased as a function of the increase of concentration of reinforcer and run time also increased as concentration increased. The data for the FI 150 s schedule indicated that PRP increased as concentration increased.

Quantity, the amount of a reinforcer also affects temporal performance. For example, Madigan (1978) exposed rats to an FI schedule that delivered one or four food pellets and manipulated the probability of each occurring. The rate of response was always higher after one pellet reinforcer was given than after of four pellets. Inversely, PRP was lower for the four food pellets than that of one food pellet. As probability of reinforcement increased, response rate decreased and PRP increased for both one and four pellet reinforcer. Together, these studies show that reinforcer magnitude has an effect on interval timing process and temporal control of behavior, such that as reinforcer duration (e.g., access duration to grain for pigeon), concentration (e.g., milk concentration), and amount (e.g., 1 pellet or 4 pellets) increases, PRP also increases and response rate decrease.

More importantly, the reinforcer magnitude effect appears to occur when intermixed within session (e.g., Staddon, 1970). Specifically, when different reinforcer magnitudes are

tested across sessions PRP become roughly equal in duration. For example, in Condition 2 of MacEwen and Killeen's (1991) experiment, pigeons were exposed to either a FI 14s or FI 35 s, with reinforcer duration of 1.5 s (access to food) for 25 session, and then reinforcer duration was switched to 3 s for another 25 session, and finally reinforcer duration was switched to 7 s for another 25 sessions. The birds' PRP duration was roughly the same across different reinforcer duration values and was dependent upon FI duration. Similarly, Hatten and Shull (1983) showed that when reinforcer duration was intermixed within session, PRP was an increasing function of reinforcer duration. However, when duration of the reinforcer was changed between sessions, there were minimal differences in PRP duration.

An important implication of these studies is that, since the reinforcer magnitude effect only appears under a within session manipulation, then there could be specific sequential dependencies between magnitude and effect on behavior in upcoming intervals. For instance, in Madigan's (1978) study intervals ended with a reinforcer of either 1 or 4 pellets. In addition, Madigan varied probability that a particular pellet-number both would occur within an interval. The trials were continuous, in that a reinforcer ends an interval and marks the beginning of the next interval. Madigan found that response rates in an interval, following a 1-pellet reinforcer was inversely related to probability of the pellet size occurring; For intervals preceded by a 4 pellet reinforcer, although mean rate was always lower than 1 pellet reinforcer, there was no simple relation to the probability. Furthermore, Madigan reported that as probability of a particular number of pellets occurred increased, PRP increased in duration. In short, Madigan's study suggests that an effect of reinforcer magnitude on behavior has different time-course depending on sequence in which it occurred. To date, there have been no studies that looking at systematical sequence effects.

The purpose of the experiment is to investigate how within-session variations in the sequence of different reinforcer durations affect temporal performance. To investigate the effects of sequence pattern, we use a method in which *number* and *spacing* of two different reinforcer durations are varied within session. This method is similar to one used by Higa (1996), studying sequential effects of interval (not reinforcer) duration. In that study, pigeons received daily sessions of 100 intervals. Two or eight intervals out of 100 were programmed to deliver FI according to15-s schedule; the remaining intervals were 45 s. The short-intervals occurred either in succession, one right after the other, or were separated by four longer intervals. A "train" of shorter intervals occurred at an unpredictable point within session. Of interest was key pecking behavior just before, during, and after transition to shorter intervals. First, short intervals decreased PRP in the next interval. Second, the average PRP duration in intervals *following* a set of shorter intervals – whether occurring in succession or spaced apart - was shorter than that those before transition. Third, PRP duration after a set of short-intervals was significantly shorter and *slower to recover* to pre-transition levels when there were many short intervals, when compared to just a few. Evidently, the effect of short intervals persisted in several longer intervals. Rats show similar patterns of responding (e.g., Higa, 1997; standard FI schedules, and longer intervals). Summarizing, under some conditions temporal behavior is based on the just-preceding interval duration. Under other conditions, timing is based on several intervals ago. If reinforcer duration changes performance in ways similar to changes in between reinforcers (i.e., FI requirement), then we expect to find similar results when reinforcer duration varies. In the present study, we varied, holding constant FI requirement, type of transition (e.g., up or down) and spacing (e.g., close or far) of reinforcer duration.

Method

Subjects

Subjects were 8 pigeons, 5 Silver Kings and 3 White Carneauxs, all supplied from Palmetto Pigeon Plant. The pigeons have all had prior experience with a variety of instrumental and timing procedures. Pigeons were placed on free food to attain ad libitum weight. Once established, their weights were reduced gradually to 80% of their ad-lib weights, by restricting their daily food intake. All pigeons were given free access to water, and were housed in individual cages. The room provided light on a 12/12-hour light dark cycle. Pigeons were run 5 to 6 days a week.

Apparatus

Four standard operant chambers (30.5 by 29 by 25 cm) were used. The operant chamber was housed in a sound-attenuating cubicle with a fan masking extraneous noise. Each chamber was fitted with an automatic food dispenser (magazine) and access to food was available through an aperture in the front panel measuring approximately 5 by 6 cm, located on the front panel. Each chamber was also equipped with three response keys, measuring 1in diameter. The center key was located approximately 12.5 cm above the food aperture, and was illuminated during each interval, and was unlit during reinforcer availability. Other keys were inactive. The house light remained lit throughout sessions. An IBM-compatible computer, using a program written in MED-PC, controlled experimental events in an adjacent room. All responses and experimental events were recorded and collected via this computer.

Procedure

Table 1 shows conditions and order for all the subjects. All pigeons started on baseline FI 60 s with reinforcement magnitude set to four seconds for 10 sessions. Each session contained 40 intervals and began with four seconds of a “free” (non-contingent) reinforcer. Both baselines

were labeled M. After the first reinforcer was given, a program timer began and reinforcement was given for the first peck after 60 s elapsed since the start of the interval. During baseline, the programmed interval and RD together were 64 s in duration that is, 60 s for the time to RD plus four seconds for RD. The top panel of Figure 1 shows an example of the RD across intervals for both baseline conditions

Subjects were then exposed to one of four experimental conditions. Each condition consisted of transitions, either up or down. During up transitions (labeled L) the ratio was 1:2 where reinforcement duration increased from four to eight seconds. Down transitions (S) was constructed the same as up transition with the exception of ratio being 2:1, decreasing RD from four to two seconds. The conditions also differed in terms of spacing of different (shorter or longer) RDs, either close or far. Close spacing consisted of five consecutive intervals of transition either up or down (C). Far spacing was constructed by having each interval of a RD transition separated by two intervals of non-transition or pre-change RD and sequence was used until five intervals of transition had occurred (F).

All pigeons experienced each condition. The order of conditions was counterbalanced using a Latin-Square Design. The first transition in RD varied within a session between the11^{th} and 26^{th} interval for close conditions and 11^{th} and 17^{th} interval for far conditions of spacing sequence. CMLM, close spacing with medium reinforcer duration and an increase of RD for five intervals and decrease of RD to the medium is shown in Figure 1, middle panel. CMSM (figure 2 top panel), FMLM (figure 1 bottom panel), and FMSM (figure 2 bottom panel). After all Experimental conditions, a final baseline condition was conducted.

Subjects	Order of Conditions
8118, 6213	B1 (10) → CMLM (10) → CMSM (10) → FMLM (10) → FMSM (10) → B2 (10)
1021, 9069	B1 (10) → CMSM (10) → FMLM (10) → FMSM (10) → CMLM (10) → B2 (10)
264, 5628	B1 (10) → FMLM (10) → FMSM (10) → CMLM (10) → CMSM (10) → B2 (10)
9459, 9109	B1 (10) → FMSM (10) → CMLM (10) → CMSM (10) → FMLM (10) → B2 (10)

Table 1. Depicts, by subject number, the order by which the conditions were ran, each condition was conducted for 10 sessions.

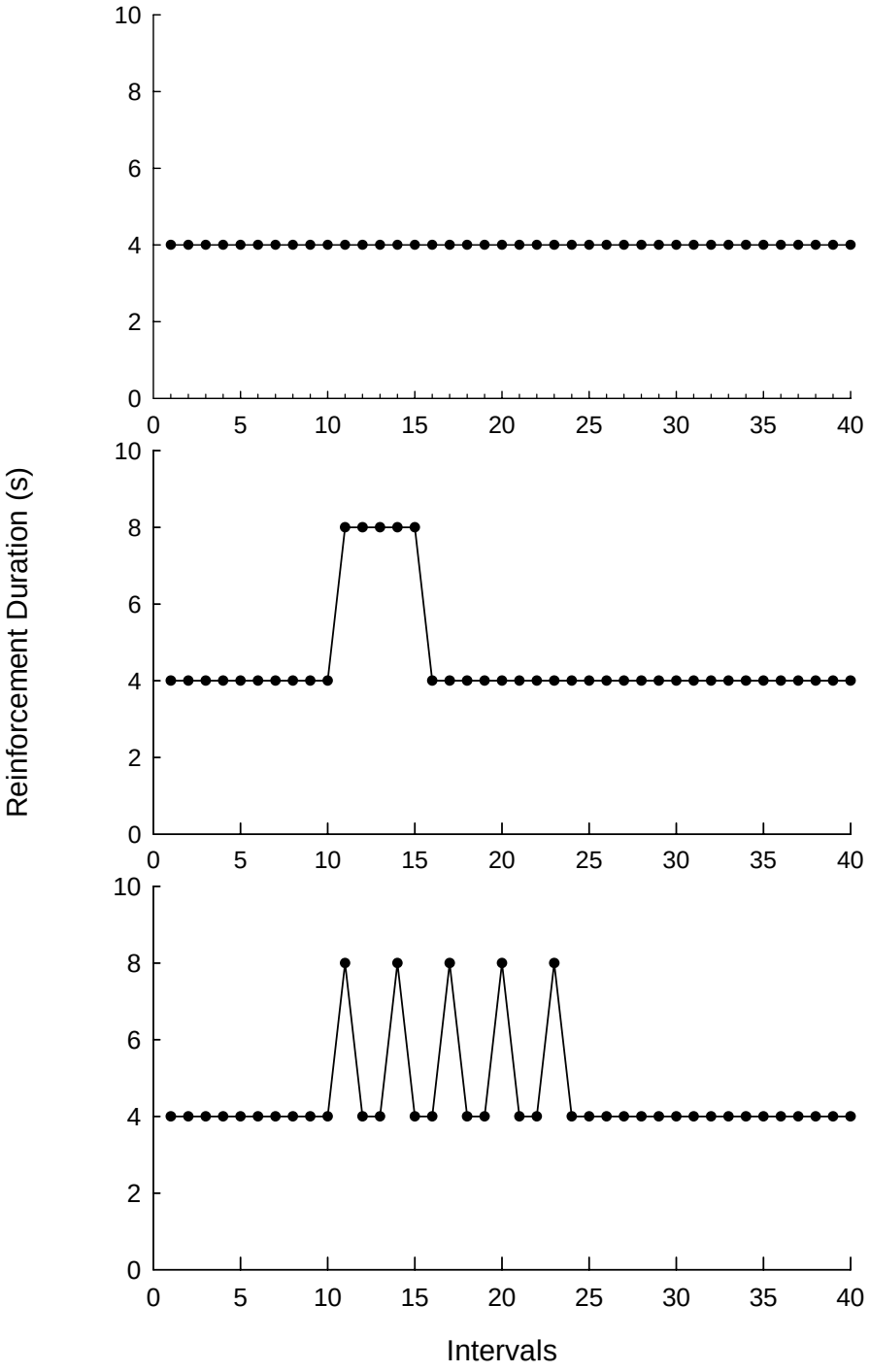

Figure 1. Examples of experimental conditions: top panel is the baseline, middle panel CMLM, and bottom panel FMLM.

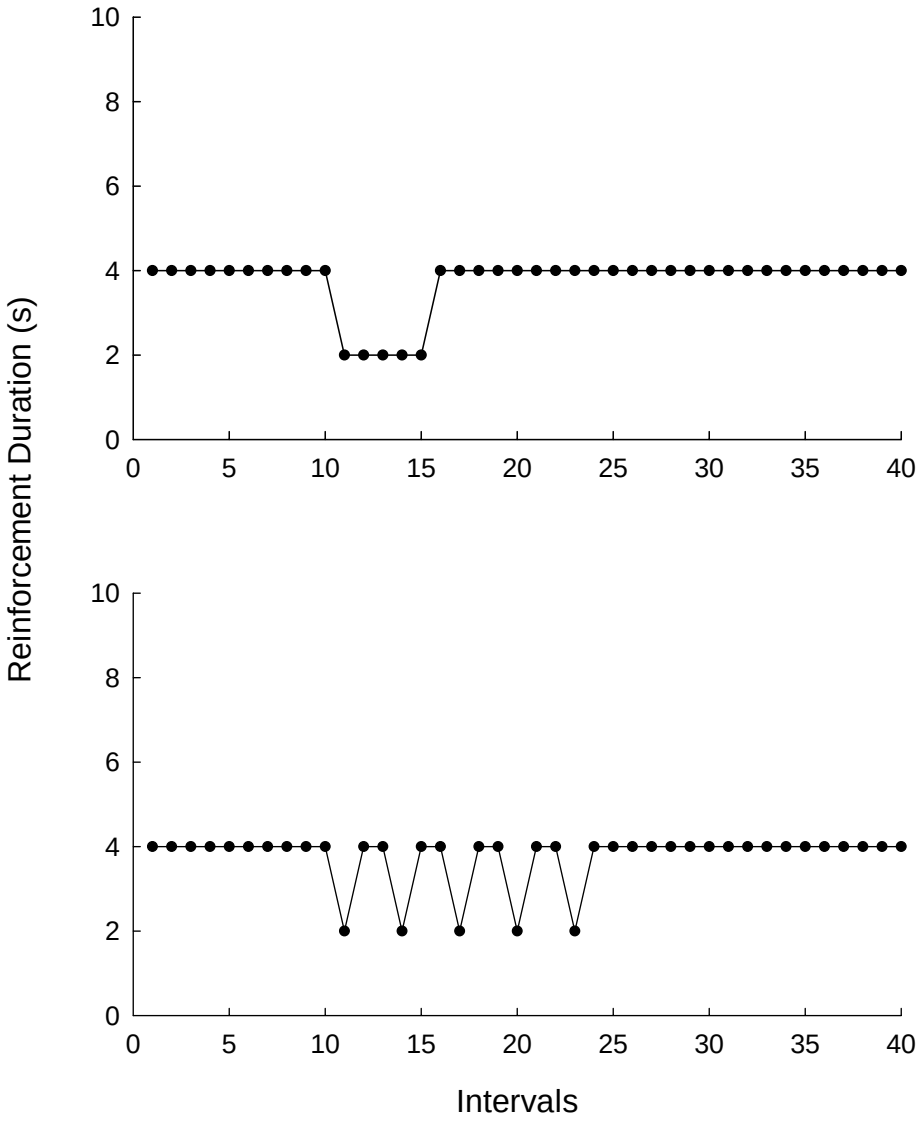

Figure 2. Examples of experimental conditions: top panel is the CMSM and bottom panel FMSM.

Results

We analyzed the data and looked at two different measures of timing behavior: PRP and response rate in an interval. For baseline conditions, we present PRP and rate in all intervals. However, for experimental conditions we used a subset of intervals due to variations in the point of a transition across sessions occurred at different intervals. Specifically, we analyzed ten intervals before transition, intervals that included a transition, and ten following completion of a transition for each bird. For close conditions, our analysis involved 25 (out of 40) intervals and for far conditions the number of intervals was 33 (out of 40). The exception consisted of instances when a bird did not respond in an interval. Such "non-response" intervals occurred less than 1 percent of all intervals analyzed, 14 of 1920 intervals. These intervals were excluded due to being empty sets or cells. In all of our analyses, of interest is the RD effect on the temporal control of behavior in the following interval. Finally, for all analyses, we used data from all sessions of exposure.

Baseline

The top and bottom of Figure 3 depicts mean PRP across intervals shown for individual birds and group mean for Baseline 1 and Baseline 2, respectively. The figures show differences in overall PRP across subjects ranging from around 14.29 s in bird 9109 of Baseline 1 to 33.37 s in bird 9459 of Baseline 2. There were no consistent differences in PRP across intervals. However, when comparing overall PRP levels of responding across the two baselines, there appears to be an increase of PRP from about 23.63 s in Baseline 1 to 28.36 s in Baseline 2. A two-way repeated measures analysis of variance (ANOVA) was conducted on data from these baseline sessions testing effects of baseline conditions and interval number. In all our analyses, alpha level was set to .05. PRP in intervals across Baseline 1 and Baseline 2 were not significant,

$F(39,273) = 1.159$, $p = .248$. Although, overall PRP was significantly larger in Baseline 2 than in Baseline 1, $F(1,273) = 10.045$, $p < .05$.

The top and bottom panels Figure 4 depicts individual and group mean response rate in intervals from Baseline 1 and 2. Looking across intervals from Baseline 1 and Baseline 2 indicates no systematic change in rate, a two-way Repeated Measures ANOVA was conducted and was not significant, $F(39, 273) = 2.518$, $p = .157$. When Baseline 1 and Baseline 2 were compared there appeared to be decrease in overall rate of response from approximately 35 to 28 responses per minute, and the difference was significantly different, $F(1, 273) = 3.189$, $p < .05$.

Transition Conditions

Figure 5 shows mean PRP for all individual subjects and group across selected intervals. The top and bottom of Figure 5 shows condition CMLM and CMSM, respectively. The dotted lines indicate the location of transition intervals in each condition. Looking across intervals by condition suggests moderate increase of PRP for condition CMLM during longer RD values from about 25 to 27 s and more noticeable decrease of PRP during shorter RD intervals in CMSM condition from around 26 to 21 s. A two-way repeated measures ANOVA was conducted and indicated that there was not a significant difference in overall PRP duration across conditions, $F(1, 168) = 0.704$, $p = .429$. However, there was a significant main effect of interval, $F(24, 168) = 1.819$, $p < .05$. For example, when comparing interval 5 (which began with a 4 s RD) to 15 (which began with a 2 s RD) in the CMSM condition, a Student-Newman-Keuls (SNK) pair-wise comparison was significant ($q = 6.103$, $p < .05$) also, intervals 15 and 16, at the end of transition of RD, were significantly different ($q = 6.456$, $p < .05$), and intervals 9 and 11, at the beginning of the transition of RD, were significantly different ($q = 5.192$, $p < .05$). SNK comparison conducted on intervals in CMLM condition indicated no significant difference. An ANOVA also indicated that there was a significant interaction between conditions and interval,

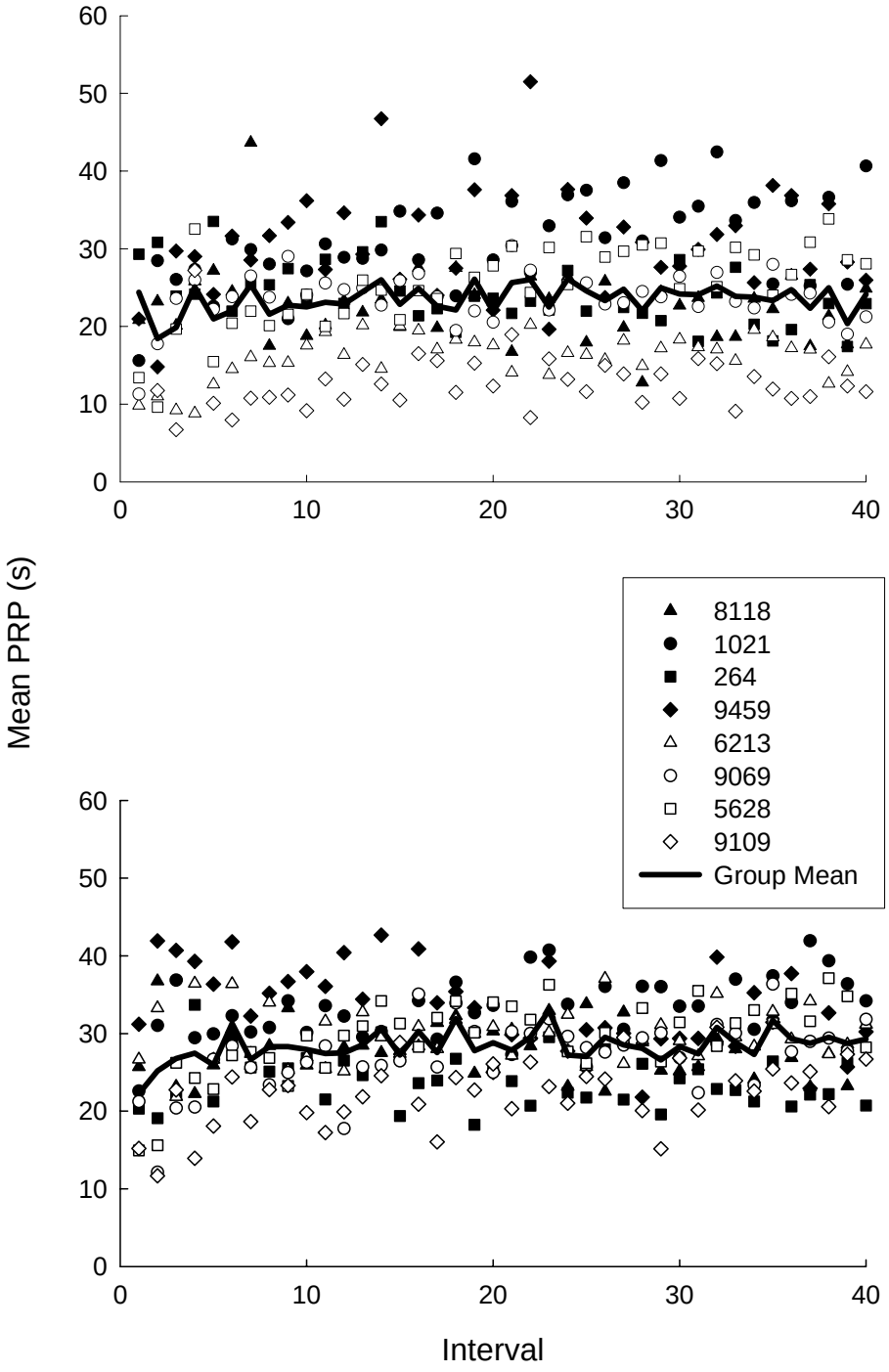

Figure 3. Mean PRPs for individual subjects and group shown across intervals for all sessions. Top panel is Baseline 1, before the transition conditions. Bottom panel is Baseline 2, after the transition conditions.

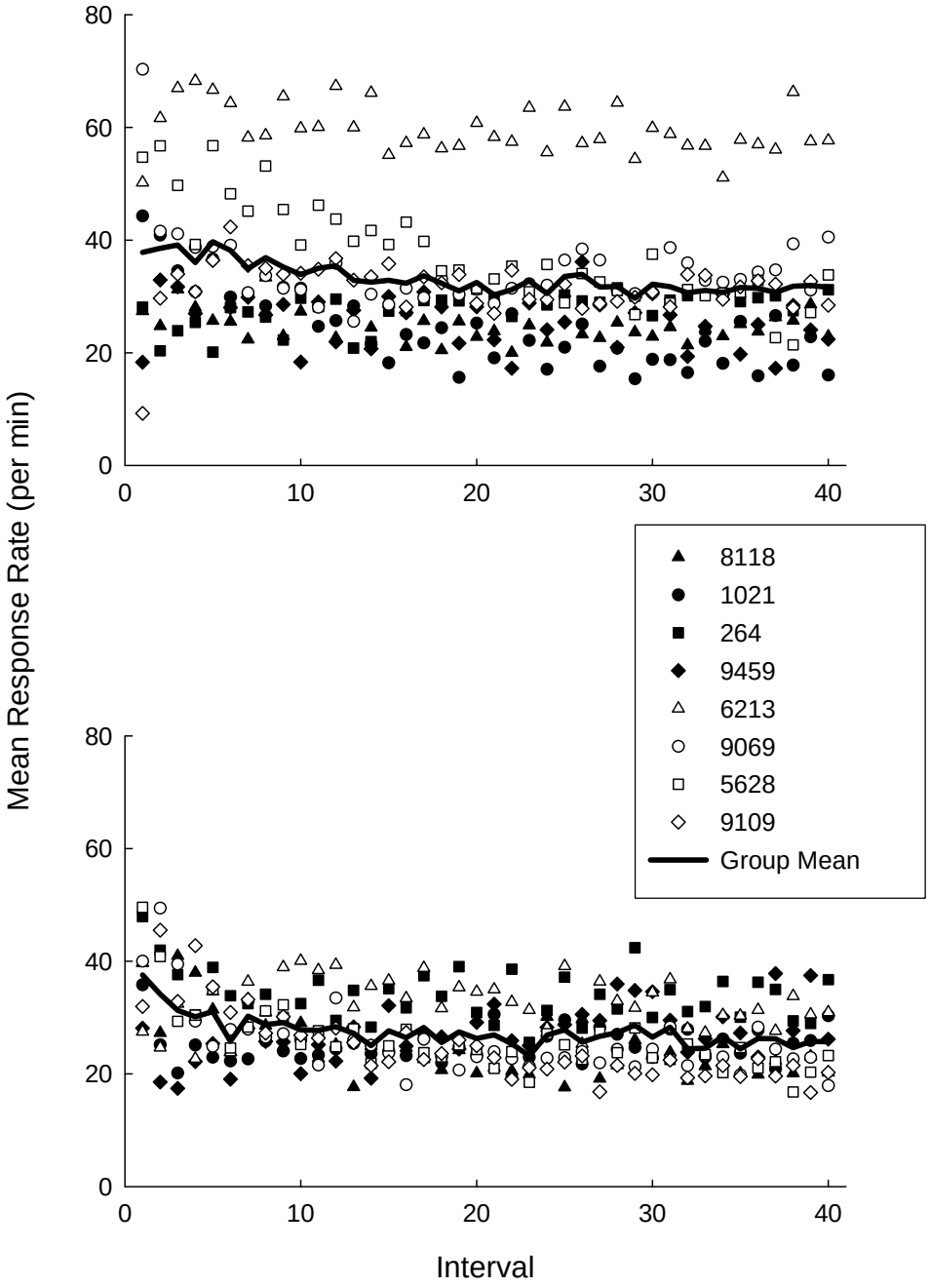

Figure 4. Mean response rate for individual subjects and group shown across intervals for all sessions. Top panel is Baseline 1, before the first transition condition. Bottom panel is Baseline 2, after the last transition condition.

$F(24, 168) = 2.270$, $p < .05$. For example, comparing transition of RD of both conditions within interval 12 was shown to be significant ($q = 4.480$, $p < .05$). Finally, there were no significant differences in PRP during intervals after transition.

The top and bottom of Figure 6 shows mean response rate for all subjects and group across selected intervals for conditions CMLM and CMSM, respectively. Comparing overall response rate for conditions indicated they were not significantly different using an ANOVA, $F(1, 168) = .245$, $p = .636$. However, testing response rate in intervals within condition type was significant, $F(24, 168) = 1.859$, $p < .05$. There appears to be a small decrease of response rate in the middle of the transition of RD to 8 s and slowly recovers after RD decreases to 4 s, but the change was not significant. For CMSM condition, response rate starts around 27 and increases to about 30 responses per minute at intervals where RD decreased to 2 s and rapidly decreases down to about 26 responses per minute at intervals where RD increases to 4 s. There was a significant difference in response rate between interval 11 (where RD started at 2 s) compared to interval 5 (where RD started at 4 s, $q = 5.121$, $p < .05$), and interval 16 ($q = 6.981$, $p < .05$). There was a significant interaction between response rate in conditions and intervals, $F(24, 168) = 2.237$, $p < .05$. For example, there was a significant difference between response rates in conditions in interval 11(transition of RD to 2 s, $q = 5.244$, $p < .05$). Before or after the transition of RD between conditions for any other interval were not found to be significant.

The top and bottom panels Figure 7 shows mean PRP for all individual subjects and group across selected intervals for all sessions for conditions FMLM and FMSM, respectively. Overall, there were no significant differences between overall PRP duration across conditions, $F(1, 224) = 1.818$, $p = .220$. Looking at condition FMLM, there was slight increases in PRP from

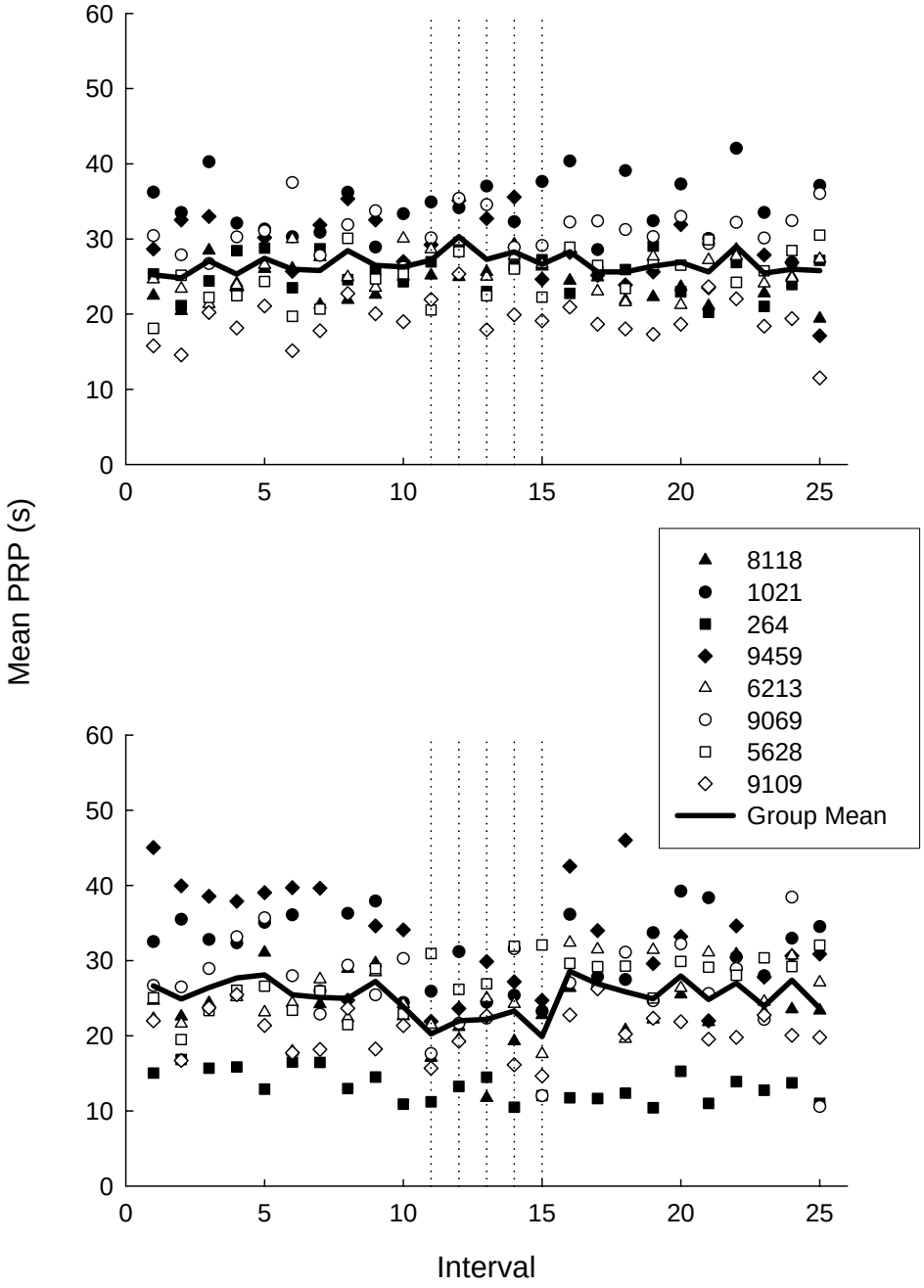

Figure 5. Mean PRP for individual subjects and group across all sessions. Top panel is CMLM. Bottom panel is CMSM. The dotted lines indicate the intervals of transition in reinforcer duration.

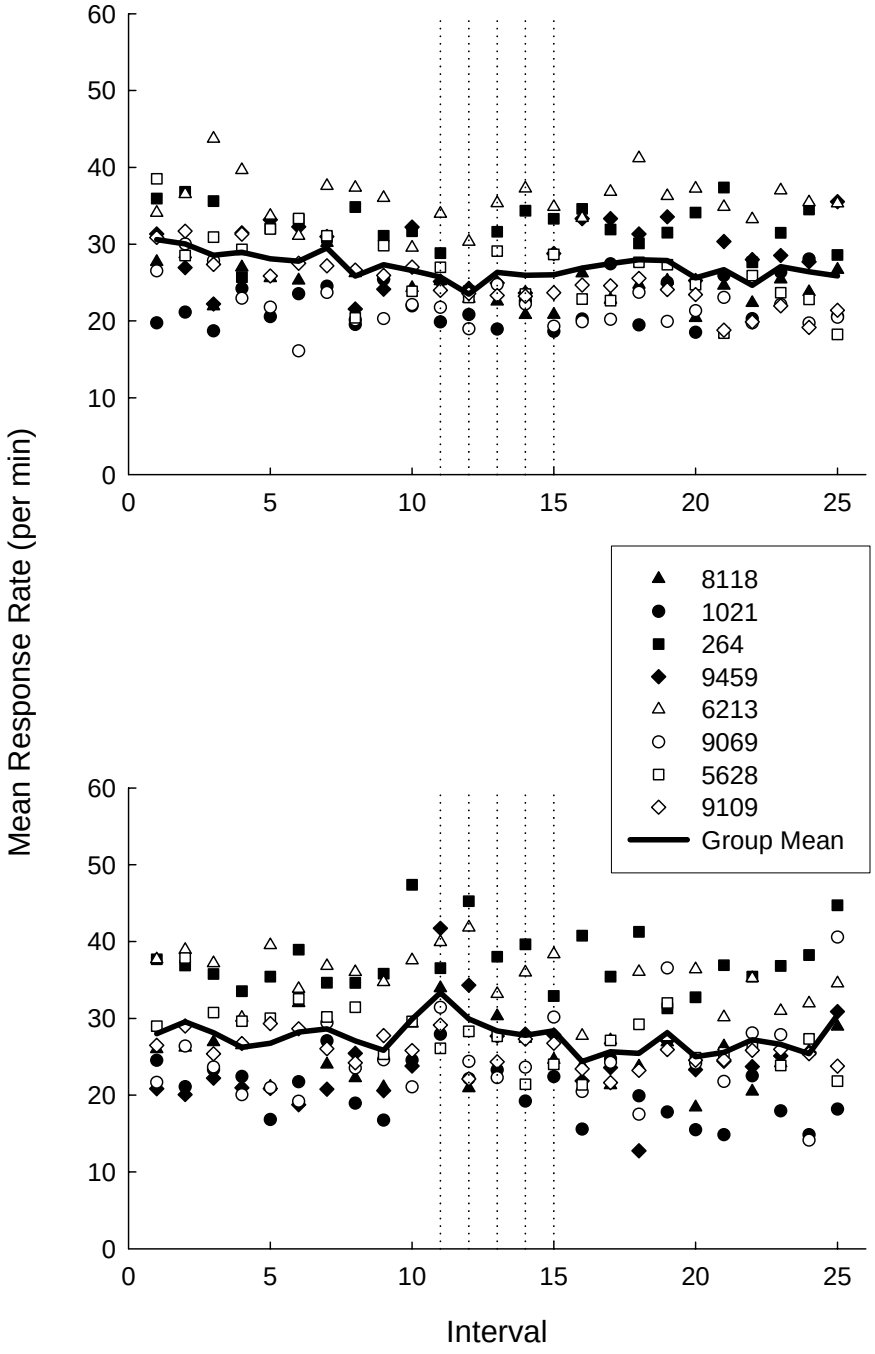

Figure 6. Mean response rate for all subjects and group across intervals for all sessions. Top panel is CMLM. Bottom panel is CMSM. The dotted lines indicate the intervals of transition in reinforcer duration.

$F(1, 224) = 1.818$, $p = .220$. Looking at condition FMLM, there was slight increases in PRP from about 28 to 31 s across intervals where RD increased from 4 to 8 s and continues to stay slightly elevated peaking at around 33 s and was quick to recover to RD of 4 s. However, these effects were not consistently different. For condition CMSM, intervals where RD decreased from 4 s to 2 s, there seemed to be rapid (across one interval) decrease in PRP from about 25.82 in interval 10 to 22.52 s in interval 11 and quick recovery in interval 12 where RD increased to 4 s and PRP was about 28.40 s. PRP was significantly different among intervals decreasing in RD to 2 s and intervals where RD was 4 s, for example, comparing intervals 20 to 21 there was a significant increase in PRP, ($q = 5.682$, $p < .05$). There was a significant interaction of PRP between condition type and interval, $F(32, 224) = 2.686$, $p < .05$. For example, PRP within condition types were significantly different at intervals 11 ($q = 5.253$, $p < .05$), 14 ($q = 3.978$, $p < .05$), 17 ($q = 5.860$, $p < .05$), 20 ($q = 5.402$, $p < .05$), 23 ($q = 4.462$, $p < .05$) and not significant at any other intervals.

The top and bottom panels of Figure 8 show mean response rate for all subjects and group across selected intervals for conditions FMLM and FMSM, respectively. Comparing conditions, overall response rate across intervals was not significant, $F(1, 224) = 1.033$, $p = .343$. However, looking at response rate between intervals of conditions indicated a significant difference, $F(32, 224) = 2.107$, $p< .05$. In condition FMLM, response rate decreased slightly from interval 1 to interval 16 (where RD increased to 8 s in intervals 11 and 14) from around 27 to 25 responses per minute. There seemed to be no clear change until interval 17 (where an increase in RD to 8 s), which response rate decreased from about 25 to 23 responses per minute. Beyond interval 17 there was no notable differences. In condition FMSM, intervals where RD decreased from 4 s to 2 s show more abrupt increase in response rate and faster recovery in the following interval. For example, in interval 23 (where RD was 2 s) response rate was

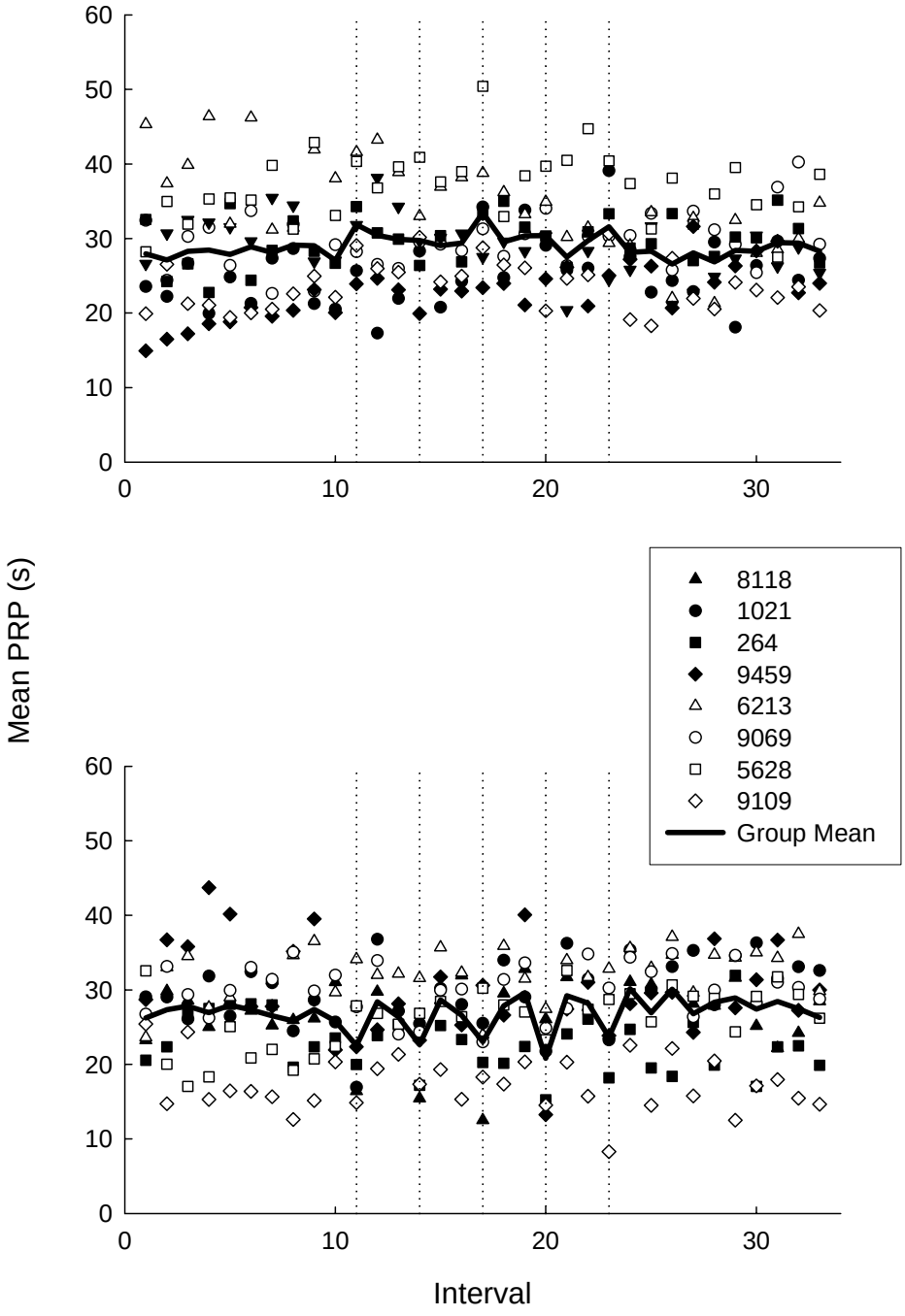

Figure 7. Mean PRP for all individual subjects and group across intervals for all sessions. Top panel is FMLM. Bottom panel is FMSM. The dotted lines indicate intervals of transition in reinforcer duration.

approximately 27 responses per minute, in the following interval response rate decreases to about 23 responses per minute. These changes were significant using a SNK pair-wise comparison. For example, intervals 20 and 21 the response rates were significantly different from one another ($q = 5.493$, $p < .05$). There was a significant interaction of response rate between conditions and intervals, $F(32, 224) = 2.421$, $p < .05$. Difference of response rate between conditions in most all intervals where RD decreased from 4 s to 2 s indicated significance (with the exception of interval 11 ($q = 2.562$, $p = .078$) not significant), 14 ($q = 3.140$, $p = .05$), 17 ($q = 4.019$, $p < .05$), 20 ($q = 4.580$, $p < .05$), 23 ($q = 4.012$, $p < .05$).

Discussion

The purpose of our study was to examine sequence (either far or apart) and change in duration (decrease or increase) of a reinforcer on PRP duration and response rate behavior of pigeons. One goal was to investigate that timing behavior was sensitive to within session changes of RD. The second goal was to examine sequencing of RD changes on timing behavior; such that changes of RD was either consecutive for five intervals or between each of the five intervals were separated by two intervals of pre-RD change. Another goal was to determine whether or not pigeons were tracking using preceding interval (one back tracking) or using more than just the preceding interval. The final goal was to ascertain the existence of molar effects of timing behavior by examining PRP duration and response rate between Baseline 1 (before experimental conditions) and Baseline 2 (after experimental conditions).

First, our study has shown that changes in RD (increase or decreases) affects PRP duration (increase or decreases) and response rate (decreases or increases), but only under certain conditions. Specifically, conditions when RD deceases from four seconds to two seconds within session, PRP duration was shown to decrease and response rate increases. These findings are

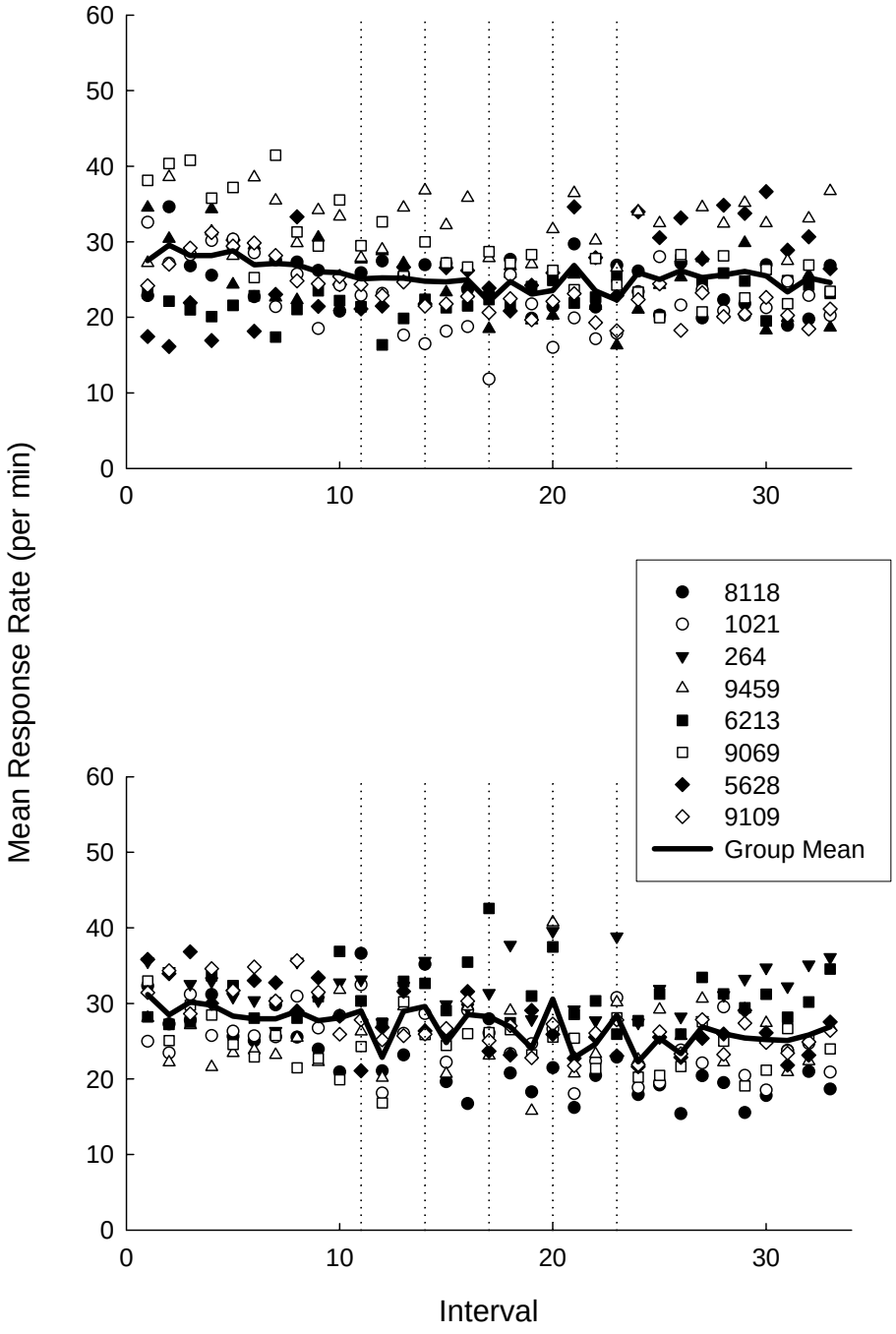

Figure 8. Mean response rate for all subjects and group across intervals for all sessions. Top panel is FMLM. Bottom panel is FMSM. The dotted lines indicate intervals of transition in reinforcer duration.

consistent with results from previous studies showing that PRP duration and response rate (e.g., Staddon, 1970; Lowe, et al., 1974; Madigan, 1978) are affected by changes in RD.

Also, our study depends on minimal changes in PRP duration and response rate as RD increased. What was expected was that PRP should increase and response rate should decrease as RD increased from 4 to 8 s. A possible explanation for minimal changes of PRP duration and response rate is that absolute difference between RD transitions of change (M→L) was not great enough to track. Although if the detection of absolute change were the case then animals should not have tracked RD decrease from 4 to 2 s. Temporal control of behavior could depend upon relative changes in RD or the interval plus the RD or absolute changes of RD changes. To illustrate, Ludvig and Staddon (2005) investigated how tracking depends on relative and absolute changes. Ludvig & Staddon reported that pigeons were able to track cyclic 12 FI short (5 or 30 s) and 12 FI 180 s readily, but pigeons did not track single-alternation of a FI 30 and FI 180 s schedule very well. Pigeons did track the FI short of five seconds as pigeons adjusted their PRP duration to anticipate the upcoming interval. Although, when the FI short duration was 30 s pigeons were not able to adjust PRP duration to the upcoming interval as well. Thus, the possibility that pigeons in our study based their PRP on absolute instead of relative changes could account for their minimal change of PRP and response rate.

Next, sequence of intervals where RD changes (increases and decreases) also had an effect on timing behavior in pigeons. For example, in the condition CMSM pigeons were able to track a decrease in RD, for five consecutive intervals pigeons tracked RD change, decreasing PRP duration and increasing response rate. Similar findings were reported by Higa & Pierson (1998) as an increase of the number of shorter intervals durations are administered within a set of lager interval fast acquisition, next interval, to the original interval duration occurred. Also, in

our study we reported that when separating intervals where RD decreases with two intervals or original RD that tracking was fast acting.

Another factor that could be involved in temporal control is if the pigeons are using one-back tracking for sequential changes of RD or using more than just the preceding interval. In our study, as RD decreases for five intervals each separated by two intervals of original RD value indicated that pigeon were using one-back tracking. Higa and Peirson (1998) and Higa, Moreno, & Sparkman (2002) reported that changes in interval duration number have an effect on recovery to pre-transition interval duration. The more changes of interval duration consecutively conducted the slower (more intervals) reacquisition to pre-transition levels.

Lastly, we reported that when comparing Baseline 1 (pre-experimental conditions) and Baseline 2 (post experimental conditions), although conditions showed stable responding across intervals, PRP increased from pre to post experimental conditions duration and response rate decreased from Baseline 1 to Baseline 2 occurred. The result suggests an indication that after animals had experienced each of experimental conditions a molar experience of experimental conditions had a lasting effect on PRP and response rate. These finding were similar to Higa, Thaw, & Staddon (1993) where in Experiment 2 overall PRP duration decreased across sessions after exposure to a three different interval durations. Higa, et al., suggested that not just the preceding interval affects overall behavior, but could also encompass prior intervals. It may be that a similar effect occurred in the present study. Specifically, looking at the overall PRP decreasing in duration from Baseline 1 to Baseline 2.

Future directions should encompass increasing the number of intervals where RD changes, especially when increasing RD, because increasing changes of PRP duration increases the probability for more reinforcement (e.g., Madigan, 1978). Another possibility would be to vary absolute and relative changes of RD. Relative changes may increase tracking efficiency

(Ludvig, et al., 2005). Also, increasing intervals between RD changes, for example, increasing from two to four intervals of pre-change RD, could change tracking efficiency by animals incorporating one-back tracking instead of molar experience (e.g., Higa, et al., 1998). Another direction would be to separate RD changes (increases or decreases) by varying number of intervals that are of pre-RD change. For example, separating RD change with varying numbers, such as three, one, four and two intervals of pre-RD change randomly within session. The results from our study and those of previous studies would lead to predict that animals would be able to track the dynamic sequence depending upon absolute or relative changes and direction of RD by altering their timing behavior to incorporate tracking of the preceding interval (e.g., Higa, 1996; Ludvig, et al., 2005; Higa, et al., 1998).

In conclusion, within session changes in RD transition and sequence have an effect on timing behavior, specifically PRP duration and response rate. That changes in RD have an effect on timing behavior is interesting because RD should be an irrelevant variable, because the reinforcer was used as a signal for the onset and offset in the interval. Instead, our results suggest that RD was used as a *time marker* (e.g., Staddon, 2001) or stimulus by which time is marked. The results form our study reveal important properties of timing mechanisms under dynamic conditions, such as when the direction of RD change, absolute versus relative change, and implication for theories of timing (e.g., one-back tracking, molar timing, and time markers).

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VITA

Darius Dean Donohue was born November 22, 1973, in Claremore, Oklahoma. He is the son of William Charles Donohue and Laurie Ann Heffelman. A 1992 graduate of Stillwater High School, Stillwater, Oklahoma, he received a Bachelor of Science degree with a major in Psychology from Oklahoma State University in 2003. While in attendance he became involved with research in the laboratory of Dr. Charles I Abramson, of which he attained his first publication and award from Sigma Xi for research, also, while at Oklahoma State University presented a poster at SWPA and OPS.

After receiving the Bachelor of Science in Psychology he attended Texas Christian University in Fort Worth, Texas in 2003. While in attendance he conducted research in the laboratory of Dr. Jennifer Higa. Presented poster at ACES and was involved with two other posters that year. In the following year he went to the University of Texas Arlington, Arlington, Texas (2004). There he worked in the laboratory of Dr. Perry Fuchs and Dr. Yuam Bo Peng conducting research with electrophysiology and small animal manipulation.

In the following year (2005) he went back to Texas Christian University, Fort Worth, Texas and work in the laboratory of Dr. Jennifer Higa once more. During this year he presented a poster at SWPA/SCPA and ABA. He is now finished with his Master of Science degree.

He is married to Kelly Dawn Donohue and has one child.

ABSTRACT

ANALYSIS OF REINFORCEMENT DURATION SEQUENCE

ON TEMPORAL TRACKING

IN PIGEONS

By Darius D. Donohue, 2006

Department of Psychology

Texas Christian University

Thesis Advisor: Jennifer J. Higa, Associate Professor Psychology

Pigeons' ability to track changes of reinforcement duration (RD) and spacing of changes within a session, such as close (consecutive intervals) and far (each change in reinforcer duration was separated by two intervals of four seconds RD), was the focus of the study. Pigeons were exposed to two baseline conditions, one before and after experimental conditions. The four experimental conditions consisted of changes of RD and sequence (consecutive and separated) and each pigeon experienced each condition. The results indicated that tracking was directional. Specifically, when there was a decrease in reinforcer duration (i.e., four to two seconds). Pigeons readily tracked changes of reinforcer duration in the following interval, indicating one-back tracking. The implication of our study suggests that changes of RD within a session were used as a time marker for when to respond in the next interval for reinforcement.