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### Dynamics of human fixed-ratio performance

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DYNAMICS OF HUMAN FIXED-RATIO PERFORMANCE

By

Andrew E. Nuzzolilli

Applied Behavior Analysis M.S., Western New England University, 2017

Dissertation

Submitted to the Department of Psychology  
and the College of Arts and Sciences at  
Western New England University in partial  
fulfillment of the requirements for the  
Degree of Doctor of Philosophy

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Dr. Jonathan W. Pinkston, Committee Chair

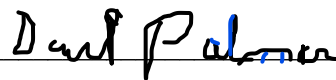


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Dr. Annie Galizio, Committee Member

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Dr. Jason C. Bourret, Committee Member



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**Abstract**

Human sensitivity to fixed-ratio (FR) schedules was examined in terms of running rate, pre-ratio pause (PRP), inter-response time (IRT), response force, and verbal behavior. College students pressed a force transducer to produce access to video media under a variety of multiple FR schedules. During Experiment 1, ten students participated in a single session with juxtaposed small (FR 5) and large (FR 20, 40, and 80) schedules. For all participants except two, running rate was faster during the large ratio. Response latencies, subsuming both PRP and IRT, decreased within session. Response force also tended towards smaller values when comparing early and late session. During Experiment 2, five participants returned for many sessions to permit within-subject comparison of responding at different ratio sizes. Sensitivity was observed as changes in running rate closely tracking changes in ratio sizes, within-session decreases in both latency and response force, and correlated changes in participant verbal behavior. Across both experiments, biphasic FR performance characteristic of experiments with non-humans was reproduced in that post-ratio pausing was typically longer than subsequent IRTs. However, unlike previous non-human research, PRPs did not increase with changes in ratio requirement.

Key words: Fixed-ratio, Sensitivity, Running rate, PRP, Response Force, Verbal Behavior, Human

### **Dynamics of Human Fixed-Ratio Performance**

A schedule of reinforcement is a set of conditions under which a reinforcer will be produced by the environment (Zeiler, 1984). Orderly and reliable response rate functions produced by reinforcement schedules with pigeons were first described by Ferster and Skinner (1957). Over 50 years of systematic replication across non-human species and experimental conditions have further demonstrated the generality, reliability, and utility of these independent variables (Morgan, 2010; Shull and Lawrence, 2013). In basic research, reinforcement schedules are used to calibrate experimental equipment, establish a baseline to evaluate the effects of other variables, or verify that a laboratory has achieved sufficient experimental control to conduct further study (Sidman, 1960). Beyond their basic utility, schedules of reinforcement and the response patterns they produce are of importance in theory (Zeiler, 1984) and broad application to human affairs (Skinner 1938, p.441; Skinner 1953).

Simple schedules of reinforcement – fixed and variable; ratio and interval – are especially noteworthy for utility in generating a behavioral baseline, application to a wide range of experimental questions, and production of temporal response patterns unique to each arrangement. Originally, schedule performance was depicted on a cumulative record where changes in slope of a line corresponded to momentary changes in response rate (Ferster & Skinner, 1957). Cumulative records illustrate the fine-grained dynamics of behavior-environment interaction extended across time. These interactions produce patterns of response rate variation, among them the positively accelerated fixed interval (FI) “scallop” and the fixed ratio (FR) “staircase” produced by breaks in responding (Lattal, 1991). These response patterns are so commonly produced by these independent variables that they have become synonymous with the notion of sensitivity to the schedule itself (Baxter & Schlinger, 1990; Madden, et al., 1998).

Although temporal patterns such as those produced by FI and FR schedules are readily observed with non-humans, there is a lack of consistent experimental evidence for these patterns with humans. Some experiments conducted with humans do not replicate non-human response patterns (Blair, 1958; Weiner, 1962; Weiner, 1969; Weiner 1970), while others do (Holland, 1958; Lowe, et al., 1978; Stoddard, et al.,

1988). The inconsistent results generated research and interpretation as to the fundamental sensitivity of human behavior to contingencies of reinforcement (see Madden, et al., 1998, for a review). Moreover, they raise important questions about the continuity of behavioral processes across different species (Dymond, et al., 2003). Despite these theoretical issues, it makes sense to first ask about the conditions under which replication of non-human response patterns are likely.

Typically, schedule sensitivity is observed with preverbal children (Lowe, et al., 1983; Long, et al., 1958; Sheppard, 1969; Weisberg & Fink, 1966; see Weisberg & Rovee-Collier, 1998, for a review). Failures to replicate non-human response patterns generally occur above the age of four (Baxter & Schlinger, 1998). One interpretation is that as individuals come to behave as speakers and listeners, they either self-generate or respond to rules and social stimuli provided by others in ways that interact with the control of non-verbal performance (Blakely & Schlinger, 1987). These multiple sources of control may mask the effects of reinforcement schedules (Shimoff & Catania, 1998).

However important the role of verbal behavior with human participants, one of the reasons that sensitivity is not observed may have to do with how we define sensitivity itself. As Madden, et al. (1998) indicated, there are two conditions under which the term sensitivity is evoked in technical usage. The first refers to the replication of non-human temporal response patterns as previously described. In a second sense, sensitivity may refer to within-subject changes in behavior as a function of changes in independent variables. It is this broader sense in which human sensitivity to schedules of reinforcement may be evaluated. To this point, consideration of multiple dimensions of responding as the behavior of an individual is exposed to changes in contingencies are needed to make accurate statements about human sensitivity to the variables we arrange. To limit the field, we turn to review dimensions of FR responding only.

In an FR schedule, the first response after a fixed number of responses produces a reinforcer (Ferster & Skinner, 1957). Typically, with non-humans, there is a pause in responding that follows reinforcement delivery. These pauses are followed by an abrupt transition to high rate responding until the next

reinforcer is arranged (Derenne & Flannery, 2007; Ferster & Skinner, 1957; Lattal, 1991). Pause and run are distinct functional units. Ratio size and pausing covary: as response requirements increase, so does initial pause duration on average (Felton & Lyon, 1966). Under open economies, defined as a situation in which a reinforcer is available outside of the session (Hursh, 1980), running rates change bitonically with increases in ratio requirement (Ferster & Skinner, 1957; Boren, 1953; Barofsky & Hurwitz, 1968; Killeen, 1969).

Emitted response force also produces a consistent pattern across the fixed ratio run with non-humans. In a systematic replication of earlier work by Notterman and Mintz (1965), Pinkston and McBee (2014) revealed consistent patterns in peak and time integral of force using on FR 10 and FR 20 schedules with rats. Force was measured using a strain gauge or force transducer to allow for fine-grained examination of time-force functions (see Pinkston, 2021, for a review of this methodology). Early responses in the ratio were emitted with relatively low force. Response force systematically increased, and then decreased as responding progressed towards reinforcement. To our knowledge, these findings have yet to be replicated with human participants.

Interaction effects may also occur when two FR schedules, varying by some reinforcement dimensions, are juxtaposed in a compound schedule arrangement (Schlinger, et al., 2008; Baron, 2008). Perone and Courtney (1992) demonstrated the joint influence of previous reinforcement magnitude and the presence or absence of discriminative stimuli on FR pausing. Extended pauses were most likely when a signaled transition was programmed between a relatively rich and lean schedule, respectively. Extended pausing under rich-to-lean transitions is general and has been replicated with human participants (Bejarano, 2003; Williams, et al., 2011; Jessel, et al., 2016).

Prior research has tended to focus on single dimensions of response or relatively restricted ranges of ratio values. We sought to explore multiple response dimensions of FR performance with human participants using a range of ratio values. In our design, we incorporated means to analyze all the aspects of performance discussed above. We used a procedure described first by Perone and Courtney (1992) and

an apparatus that permitted investigation of response force to study multiple aspects of human performance in detail: Running rate, pausing, IRT, response force, and schedule interaction effects. Given the potential interaction of verbal and non-verbal behavior, we also collected samples of participant verbal behavior about the procedures in two cases.

## **Experiment 1**

### **Method**

#### **Participants**

Ten participants were drawn from an introductory psychology course research pool; all participants earned course credit for their participation. Prior to enrolling in the study, participants were informed as to the nature, benefits, and risks of participation. All procedures were reviewed and approved by Western New England University Institutional Review Board.

#### **Apparatus**

Participants sat in small room facing a 43-cm color monitor on a desk. A wireless mouse and keyboard were used to start session; these were removed once data collection began. A force transducer (Model 25G, Interface®, Scottsdale, AZ, USA) with a 2.5-cm brushed aluminum knob mounted to the sensing beam was clamped to the desk. The knob protruded approximately 5-cm over the edge of the desk. Responding was recorded by a data acquisition card with a 12-bit A/D converter (USB 6009, National Instruments™, Austin, TX, USA). Data were obtained at a resolution of 20 samples/s. Response detection was set at a value of 25 g for all sessions. As the participant pressed and withdrew their hand from the transducer, a force-time waveform was generated. The apparatus recorded a single response when force measurements rose above and then fell below a 25 g threshold. This feature made it unlikely that participants could have rested their hands on the device. From the waveform, we could calculate several measures: peak force, response duration, and area under the curve (i.e., time-integral of force;



Notterman & Mintz, 1965). All experimental events and data collection were controlled by custom software written in Labview® (National Instruments™, Austin, TX, USA).

The user interface consisted of a gray background in which schedule-correlated stimuli and video were imbedded. A 20.5 x 11.5-cm area centered on the monitor displayed preferred video. A 4-cm diameter circle above the video area served as “stimulus lamp” and was colored blue or green dependent on current schedule values. Audio was played over standard computer speakers mounted on the desk. Volume was set such that participants could not adjust it and sound was maintained at a normal volume for watching television as judged by the experimenters.

### **Schedule parameters**

Experimental sessions consisted of 37 rich or lean fixed-ratio schedule components arranged in pseudorandom order, where *rich* and *lean* refer to relatively smaller or larger ratio values, respectively. A computer program generated sequences of schedule components. Components were arranged so that each session consisted of 9 each of the following types of transition: rich to lean (RL), lean to rich (LR), lean to lean (LL), and rich to rich (RR). No more than three schedules of same type were arranged consecutively. Prior to the study, sixteen potential sequences of schedule components were generated. For each experimental session, one sequence was drawn at random at the start of each session from the pool of sixteen. This pseudo-random schedule arrangement was adapted from methods described in Perone & Courtney (1992).

Ratio requirements for the two schedule types varied across participants. Two participants responded on a multiple FR 5 FR 20, one participant on a FR 5 FR 40, and seven participants on an FR 5 FR 80. For all participants, rich and lean components were signaled by green and blue stimuli, respectively. Schedule completions for all participants, rich or lean, resulted in 30-s access to a television show of their own selection from a small library of options.

## Procedure

After completing informed consent procedures, the participant was brought into the experimental room.

The experimenter read the following set of instructions:

Before we begin, I want to show you the button you can use to interact with the computer [experimenter gestured toward the transducer]. You will watch a video. At certain times, the video will pause. You may need to interact with the computer many times or in different ways to restore the video. The most efficient way to respond in these sessions is to press the button repeatedly. Please do not touch any wires or devices other than the button. A pop-up window will appear on the screen and alert you that the session is over. At that point, you may leave the room. I can't tell you any more information about this situation. You must figure out how to interact with the computer.

The experimenter opened the computer program displaying a library of popular TV shows and vocally prompted the participant to select a television show to watch that session. Sessions began with 30-s playback of the selected video. During this interval, the experimenter gathered the mouse and keyboard and exited the room. After the initial 30-s elapsed, the video paused, and the green or blue stimulus was presented, signaling the onset of the first schedule component. Video playback remained paused until the programmed ratio requirement was satisfied by pressing the transducer. Then, playback resumed for an additional 30 s. Sessions proceeded until all 37 ratios were complete. Sessions were signaled by a pop-up window displaying the message "Session Complete! You may leave the room or find the experimenter". If the session was not completed in an hour, the experimenter would check in with the participant. For some participants, additional vocal guidance was necessary for response acquisition. These participants

would unscrew and twist the aluminum knob on the beam of the force transducer, and we reminded them that the best way to respond was to press the button repeatedly. No participants failed to complete a session in Experiment 1.

### **Dependent variables**

*Pausing (i.e., PRP).* Pausing or pause duration refers to the period from the end of reinforcement to the first response of the next ratio. Pausing was calculated as latency from the offset of reinforcement to the first response of the next ratio (i.e., post-reinforcement or pre-ratio pause; see Schlinger, et al., 2008 for a discussion of these terms).

*Run rate.* Run rate was calculated as the total number of responses in a ratio over time from first response to last. PRP is omitted from run rate calculations.

*Inter-response time (IRT).* IRT was calculated as latency, in seconds, between responses. The interval was timed from the offset of the preceding response, identified as soon as forces fell below 25 g, to the onset of the following response, identified as the point when forces rose above 25 g.

*Response force.* Each response produced a continuous waveform of force across time that was recorded and analyzed as the *time-integral of force (TF)*, calculated as the area under the curve of this waveform. Notterman and Mintz (1965) reported that peak force measurements may underestimate total effort emitted by the organism; TF provides a measure of sustained force during response execution.

## **Results**

Figure 1 compares averaged IRTs and PRPs from the last five schedule completions under rich (FR 5) and lean (FR 20, 40, or 80) schedules for each participant. For all participants, the biphasic structure of the fixed ratio schedules was apparent, but this did not vary by ratio requirement. Further detailed analyses of different transition types and their effect on PRP, revealed no systematic schedule

interaction or negative incentive shift effects as reported by Perone and Courtney (1992) and Williams, Saunders, and Perone (2011) using similar multiple schedule arrangements.

Figures 2 and 3 present individual IRTs from the first and last 5 schedule completions by ordinal response position for rich (FR 5) and lean (FR 20, 40, and 80) schedules, respectively. For most participants, IRT values across both rich and lean schedules were more variable during the first five completions than the last five completions. Leaner ratios produced greater initial and overall variation in IRT, especially for those participants that experienced FR 80 schedules. Figure 4 depicts run rates averaged across all rich and lean schedule completions. Each joined scatter shows one participant's average run rate during rich and lean ratios. For 8 out of 10 participants run rates during the lean ratios were greater on average than during rich ratios. For the remaining two participants (A3 and A5), an inverse pattern was obtained.

Figure 5 shows log TF by ordinal response position. Values are averaged across the last five ratio completions of the session. Filled and open circles depict latencies during rich and lean schedules (FR 20, FR40, and 80), respectively. There was no systematic variation in emitted time-integral of force across ratio requirements or participants. However, Figures 6 and 7 compare time-integral of force values from the first and last five schedule completions. Like IRT, for most participants, time-integral of force values were more variable during the first five completions when compared to the last five completions.

### **Discussion**

Biphasic FR performance was observed for all participants. Pausing after reinforcement (PRP) was generally an order of magnitude longer than latencies between responses (IRT). This pattern of responding replicates early non-human (Ferster and Skinner, 1957) and human (Wallace and Mulder, 1973) schedule research with a sample of college students using a different apparatus and reinforcer. For all participants, we observed a tendency towards shorter IRTs as the session progressed. These within-session changes may be interpreted as a transition state or period of response acquisition (Sidman, 1960).

More generally, the shift towards short IRTs may be interpreted as the selective effect of the reinforcement schedule unfolding across time.

For eight participants, running rate was greater on average during lean ratios (FR 20, 40, and 80) compared to FR 5. This outcome replicates early non-human examinations of the phenomena at moderate FR values (Ferster & Skinner, 1957; Boren, 1953; Barofsky & Hurwitz, 1968; Killeen, 1969). That we observed consistent run rate differences between ratio requirements and across multiple participants demonstrates that these ratio requirements were functionally distinct. Additional within-participant replication across a wider range of ratio values is needed to determine individual sensitivity to changes in ratio requirement on run rate (Madden, et al., 1998).

Unlike Notterman and Mintz (1965) and Pinkston and McBee (2014), we did not detect any systematic increases in response force as responding progressed through the ratio. This is perhaps because we captured a brief sample of behavior early in the acquisition process. However, for all participants, comparison between the first and last five schedule completions revealed systematic reductions in force. This overall tendency towards less effortful response variants replicates other research on within-session changes in response force during response acquisition (Brener & Mitchell, 1989; Brener & Carnicom, 2000).

Two features of FR responding commonly reported under FR schedules were absent from our results. First, there were no increases in PRP across the range of schedule values examined (Ferster & Skinner, 1957). This may be due to several factors. One account may be that increased pausing under increased schedule values requires multiple sessions of exposure to experimental contingencies and multiple exposures to each ratio requirement. That is, additional within-subject replication may be necessary beyond the single session. Another account may be that significant pausing is not observed until comparatively higher ratio requirements for humans (Williams, et al., 2011). Similar human-animal functional inequivalence has been observed in the delay discounting paradigm (Vanderveldt, et al., 2016).

Second, there was no noticeable effect of transitions between disparate schedules of reinforcement (Williams, et al., 2011). Previous literature suggests that transitions from rich to lean schedules of reinforcement produce longer than expected pauses as a function of two variables: the post-inhibitory aftereffects of reinforcement, and the  $S^A$  control exerted by stimuli correlated with the early ratio (Perone & Courtney, 1992). One explanation suggested by these variables for the absence of this effect is that either video consumption did not produce the same post-inhibitory aftereffects as the reinforcers employed in previous studies, or that the stimuli we programmed to function as signals of the upcoming ratio requirement did not function as  $S^A$ . Further experimentation is needed to determine whether our preparation contains these abative variables.

Taken together, the results of this experiment demonstrated that some aspects – namely, the biphasic pattern - of non-human FR performance may be replicated with human participants. An analysis of multiple response dimensions early and late in session revealed orderly reductions in IRT and force induced by exposure to the experimental contingencies. In experiment two, we sought to replicate and extend these findings by inviting participants to return for many sessions. This permitted exploration across a wider range of schedule parameters.

## **Experiment 2**

Experiment 1 showed that the procedures, apparatus, and reinforcer were suitable for human participants. There was also an indication that some aspects of non-human FR performance could be replicated in the human operant laboratory. We wanted to determine if prolonged exposure to our existing procedures would produce larger changes in our dependent variables -- pausing, run rate, and force -- across varying schedule parameters. In Experiment 2, five participants returned for no less than 15 sessions. We explored different ratio requirements within- and across- participants. Additionally, given the importance self-generated verbal accompaniments may have for human schedule performance, we recorded samples of participant verbal behavior after sessions in two cases to detect the development of rules and other verbal statements about the procedures.

## **Participants**

Five students were recruited by word of mouth in the psychology department. One participant (B3) was also enrolled in a course with the first author as instructor. Participants were compensated with money independent of performance and equivalent to \$5/hr. Participants completed at least 5 but no more than 20 sessions scheduled within 90 calendar days. Typically, participants completed 2-4 sessions a week.

## **Apparatus**

The apparatus was the same as described in Experiment 1.

## **Procedure**

The procedure was identical as described in Experiment 1, except that a) participants completed up to 20 sessions which consisted of 37 multiple schedule components, b) the disparity in ratio requirement between components was varied across sessions, c) the instructions were read only on the first day, and d) verbal self-report data were collected for two participants to assess possible relations between participant verbal behavior and performance (see Fox & Kyonka, 2017; Wanchisen, et al., 1992 for similar examples of this practice).

## **Schedule Parameters**

Table 1 depicts schedule arrangements for each participant in detail. For B1, two sessions of FR 5 FR 10 were followed by 15 sessions of FR 5 FR 80. In parallel, we conducted sessions with B2 and B3. We examined responding across more gradual shifts in schedule disparities – doubling from an FR 5 FR

10 every two to four sessions to a terminal requirement of FR 5 FR 80. For B2 and B3, we conducted a reversal from an FR 5 FR 80 to an FR 5 FR 20 after the initial doubling. B4 started at FR 5 FR 80. After 12 sessions, we explored the effects of more drastic ratio requirement disparities, doubling the ratio requirement to FR 5 FR 160 and reversing to an FR 5 FR 10. The molar amount of reinforcement remained constant across sessions, but ratio requirements were varied for B2, B3, and B4, creating both within- and between- session transitions.

For B5, a more extensive set of ratio requirements were examined. Initially, this participant was enrolled in a separate study examining the effects of a concurrent source of reinforcement on responding under multiple FR schedules, but the participant did not engage with the concurrent source of reinforcement (a cell phone) during the session. Procedures and outcomes were similar enough to be grouped together with participants B1-B4. This participant responded under an FR 16 FR 256 schedule using the same procedures as experiment 1, except that the FR 16 produced 45-s of video access while the FR 256 produced only 15-s (Williams, et al., 2011) for 6 sessions.

### **Dependent variables and data analysis**

As with Experiment 1, we examined pause duration, running rates, and time-integral of force. We also calculated overall response rates by dividing the total number of responses that occurred during session-by-session duration. In addition to these dependent variables, Participants 2 and 3 completed a brief questionnaire at the conclusion of each phase. The questionnaire evaluated participant verbal behavior about the rich and lean component stimuli and consisted of a two item, 5-point Likert scale ranging from 1 (*Strongly Disliked*) to 5 (*Strongly liked*). We also provided participants an opportunity to write about how they felt about the past session and if they had any hypotheses about the purpose of the study. A copy of the questionnaire can be found in Appendix A.



## Results

Figure 8 depicts pausing, run rate, and total rate. For all participants across all conditions, run rate was faster during relatively leaner ratios (e.g., FR 20, FR 40, FR 80 ...) when compared to FR 5. This difference increased as the disparity between rich and lean schedule components increased. Overall response rate, inclusive of total session time and pauses, closely mirrors these changes. For all participants, as reinforcement density decreased, response rate increased. There was no comparable effect observed on PRP alone across the ratio requirements examined.

Participants B1, B4, and B5 experienced the longest exposure to the same ratio requirements. When summed, PRPs were slightly longer during the lean ratios than rich ratios. This difference was small – typically less than 10 s – yet consistent. There were no substantial interaction effects when transitions between rich and lean ratios were programmed as described in the negative incentive shift literature (e.g., Perone & Courtney, 1992; Williams, et al., 2011). For these participants, lean ratio running rates remained much higher than rich ratio running rates without exception. As an exploratory analysis, B4 experienced rapid alternation between FR 5 FR 160 and FR 5 FR 10 schedules. Run rate, but not pausing, was sensitive to these changes.

Parametric analyses were conducted for B2 and B3. There was no persistent difference in summed PRPs. For these participants, response rates were differentiated across ratios and phases. Lean schedules produced faster run rates than the FR 5 schedules. As reinforcement density decreased, running rates increased. That is, we observed an inverse rate-density function. This functional relation was replicated during reversals between FR 5 FR 20 and FR 5 FR 80 for both participants.

Figures 9 and 10 show data averaged from the last five schedule completions of the FR 5 FR 10 and FR 5 FR 80 components for participants B1 – B4. These ratio values were selected as 4 out of 5 participants experienced these conditions. For both graphs, ordinal response position is depicted on the abscissa. Figure 9 depicts response latencies following reinforcement (PRP) and between subsequent

responses (IRT). For the same sample of responses, Figure 10 illustrates time-integral of force data. In general, there was little difference between rich and lean ratio responding, but more substantial differences between early and late ratio responding.

For all participants, the initial response after reinforcement was distinct in that the PRP was typically longer than subsequent IRTs. Therefore, FR responding conformed to biphasic expectations. FR 80 IRTs tended to be slightly shorter than FR 10 IRTs. For B1 and B3, the initial response was also characterized by greater-than-average time-integral of force. For B4, the relation between force and ordinal response position was reversed, such that force values increased across the ratio.

Figures 11 and 12 show participant ratings of component correlated stimuli for B2 and B3, respectively. Participant verbal responses about each phase are overlaid on these figures. For both participants, as the difference between the rich and lean ratios increased, so did the difference in ratings of the stimuli correlated with each component. Participants progressively described the lean ratio stimulus in worse terms as the ratio leaned out. Reversals to FR 5 FR 20 were described by B2 "...I am confused" and B3 "...The blue light was shorter than usual"

Figures 13-22 depict individual responses from the first and last five schedule completions of the first and last session of each ratio requirement for each participant. Generally, these graphs show the organization of dimensions of behavior at different points in time as a function of exposure to the contingencies we arranged. Figures 13 – 17 depict latencies following reinforcement and between responses, while Figures 18 – 22 show time integral of force for the same sampling of responses. Notably, for all participants across both dimensions of behavior, early session responding was more variable than late session responding.

For all participants, response acquisition was evident. That is, response latencies during the first five schedule completions were generally longer than those observed during the last five schedule completions. A similar overall reduction in time-integral of force was observed both within- and across

sessions. As with the analysis depicted in Figures 9 and 10, within-ratio changes in force and latency were also apparent for all participants. Early ratio and early session responding tended to be longer and more forceful than late session and late ratio responding. As with the previously discussed analyses, there was no effect of ratio size on these dimensions.

### **General Discussion**

Across both experiments, biphasic FR performance was observed for all participants across a range of FR values. PRPs were longer than subsequent IRTs. This outcome is consistent with early non-human research on FR schedule performance (Ferster & Skinner, 1957). Responding during the first five schedule completions was characterized by longer response latencies and forces that reduced as the session continued. In other words, performance accelerated and became more efficient as a function of exposure to contingencies of reinforcement both within- and across- sessions. This finding is also consistent with outcomes reported by Ferster & Skinner (1957, p. and Palya (1992) that examined rate changes under various simple schedules.

For B1 and B4, who experienced 10 or more sessions of exposure to FR 5 FR 80 after relatively little (B1) or no (B4) exposure to other contingencies, there was a small but consistent effect of ratio requirement on PRP duration. FR 80 pauses were longer than FR 5 pauses. The same pattern emerged for B5, who only experienced ratios of FR 16 FR 256. This result was consistent with earlier research conducted with pigeons (Ferster & Skinner, 1957; Felton & Lyon, 1966; Powell, 1968). However, the effects are small by comparison, and we did not observe them in any of the other participants from Experiments 1 or 2. This outcome suggests that repeated exposure to a particular ratio requirement may be necessary for consistent pause-ratio relations to emerge.

Time-integral of force values did not systematically vary within ratios. However, force tended to decrease within- and across- sessions. For all participants, more effort was exerted on the force transducer

during the first compared to the last five schedule completions of session. This tendency towards decreased force emission over time is evocative of a law of least effort or automatic punishment process by which effortful response variants are culled (Skinner, 1938; Pinkston, 2021). Unlike previous studies, we did not observe systematic within-ratio patterns or changes as ratio requirements were increased (Notterman & Mintz, 1965; Pinkston & McBee, 2014). Overall, there remains a paucity of research into dimensions of response force as dependent variables, and none to our knowledge conducted with human participants outside of our laboratory.

For participants B2 and B3, we also tracked changes verbal behavior as a function of changes in ratio requirement. For both, casual descriptions of the relative difficulty of the task and rating on a Likert-type scale of their preference for component-correlated stimuli changed as a function of changes in ratio requirement. These participants consistently rated stimuli associated with the leaner of the two ratios as “disliked” or “strongly disliked”. The participants also described lean ratio stimuli during FR 80 as “annoying” or even “hated” whereas earlier descriptions of the same stimulus under FR 20 was only “slightly boring” or “took longer to go away”.

When compared to animal research under similar ratio requirements, the pause following reinforcement was quite brief and we did not detect any clear differences in pause duration across the range of ratio requirements that were examined. However, run rate was highly sensitive to these same changes in ratio. We offer a few interpretations of these main outcomes.

Previous non-human research with fixed-ratio schedules has demonstrated the separability of response rates during ratio runs from pausing. In other words, they are distinct dependent variables that are sensitive to different independent variables (Barofsky & Hurwitz, 1968; Killeen, 1969). The shifts in overall rate were potentially maintained by contingent reductions in session time, as has been demonstrated with both humans (Wanchisen, et al., 1992) and non-humans (Mellitz, et al., 1983). We speculate that the fixed work requirement was detectible by participants, who then generated self-rules

(Schlinger & Blakely, 1987) to the effect of “respond as quickly as possible to finish sooner”. Adherence to self-rules would overshadow the effect of local inhibitory stimuli present in the early ratio.

Early empirical work from Ferster and Skinner (1957, pp. 116 - 117) suggests another interpretation of the overall absence of substantial PRPs in our arrangement. They probed 1-min time-outs (TOs) following FR 50 schedule completions with pigeons. During those ratios which TOs were arranged following reinforcement delivery, Ferster and Skinner reported reduction of PRP with one pigeon, and overall rate increase with another. More recently, Perone et al. (1987) examined the effects of a 30-sec TO following the delivery of sweetened milk on FR schedules with five rats. The authors observed that the TO shifted the overall distribution of PRPs towards shorter durations (2 s or less). Similar patterns were also reported by Baron et al. (1992) with rats responding under progressive ratio schedules. In the present study, it is possible that 30-s of video access did not merely function as a reinforcer alone, but also functioned as a TO from the ratio, attenuating the initial PRP and elevating response rates.

Qualitative properties of the reinforcer we used may also have abbreviated the initial PRP. Food or sexual stimuli may elicit or induce species-specific response patterns that compete with the target operant when arranged as reinforcers (i.e., adjunctive responses; Falk, 1971). These responses may persist even when they directly prevent the delivery of reinforcement (Williams and Williams, 1969). Thus, emission of these responses elicited by using biologically relevant stimuli may contribute to overall PRP duration observed under any schedule of reinforcement when using non-human participants. These responses would be absent when using a form of visual stimulation as reinforcement. Put simply, all that our participants had to do was look at a screen, and no additional response beyond visual orientation was needed to produce or consume that reinforcer. Research employing weak forms of visual stimuli as reinforcement with animals reveals that drugs such as nicotine (Raiff & Dallery, 2009) and methamphetamine (Gancarz, et al., 2012) establish the value of visual stimuli as reinforcers, and absent these drugs, reinforcing value deteriorates quickly (Lloyd, et al., 2012). Additional research is needed to directly compare the effects of weak visual reinforcement and more biologically relevant stimuli.

A third interpretation also applies more broadly to human operant research. As discussed by Williams et al (2011) and elsewhere (Baron & Perone, 1982; Baron, et al., 1992), it is still unclear what a human operant procedure is supposed to look like or how variables are to be arranged to create functional equivalence between human and non-human procedures. Thus, differences in procedure – rather than species -- may account for the differences in outcomes that we obtained. When contrasted with an iterative history of apparatus being designed by repeated interaction between experimenter and animal across experiments in non-human research (Skinner, 1956), little remains in common in the selection of experimental arrangements in human operant studies. Future research should continue to explore the design of human operant procedures but also strive to minimize the extent to which procedures vary.

One limitation of our study was that we were not able to attain differences in pausing as a function of the ratio values examined. In everyday life, ratio-like schedules may extend into the thousands of responses or chains of responses for a single primary or conditioned reinforcer. Thus, it is possible that the ratio requirements we examined were simply too small to observe an inhibitory effect of the early ratio. Furthermore, learning history of responding under extreme ratios and verbal behavior about the situation is unique to each participant, so future research could first empirically identify functionally distinct ratios titrated to each participant by an analysis of breakpoint under progressive ratio schedules (e.g., Hodos, 1961). The effects of an array of ratio requirements at various percentages of breakpoint could be examined for each participant and facilitate cross-participant and cross-species comparisons.

Another factor to consider in future research is the availability of reinforcement outside of the experimental context (e.g., Hursh, et al., 1988). The influence and interaction between sources of reinforcement within and outside of operant experiments has been usefully framed in terms of microeconomic concepts (see Hursh, et al., 2013 for a review). Although a complete treatment of these concepts would be beyond the scope of the present paper, one major difference between human and non-human research is simply the availability of alternative and competing sources of reinforcement that may impinge on experimental performance. The present experimental arrangement approximates an open

economy, in that the class of reinforcing events manipulated in the experiment is freely available elsewhere. Future research could directly compare schedule performance in open and closed economies with human participants.

Although there were procedural, methodological, and species-relevant differences, aspects of the behavior of the participants in this study came under the control of independent variables we arranged. Running rate was especially sensitive to changes in FR requirements. Within-session analysis revealed orderly patterns of latency and force reduction for all participants. Still, dimensions of performance produced in non-human research were absent. Pausing and response force were generally insensitive to changes in contingencies. This suggests that these dimensions of performance are distinct functional units under control of different controlling variables, even in a relatively simple laboratory arrangement such as this. Additional research is needed to examine the conditions under which these aspects of FR responding are reproduced by human participants.

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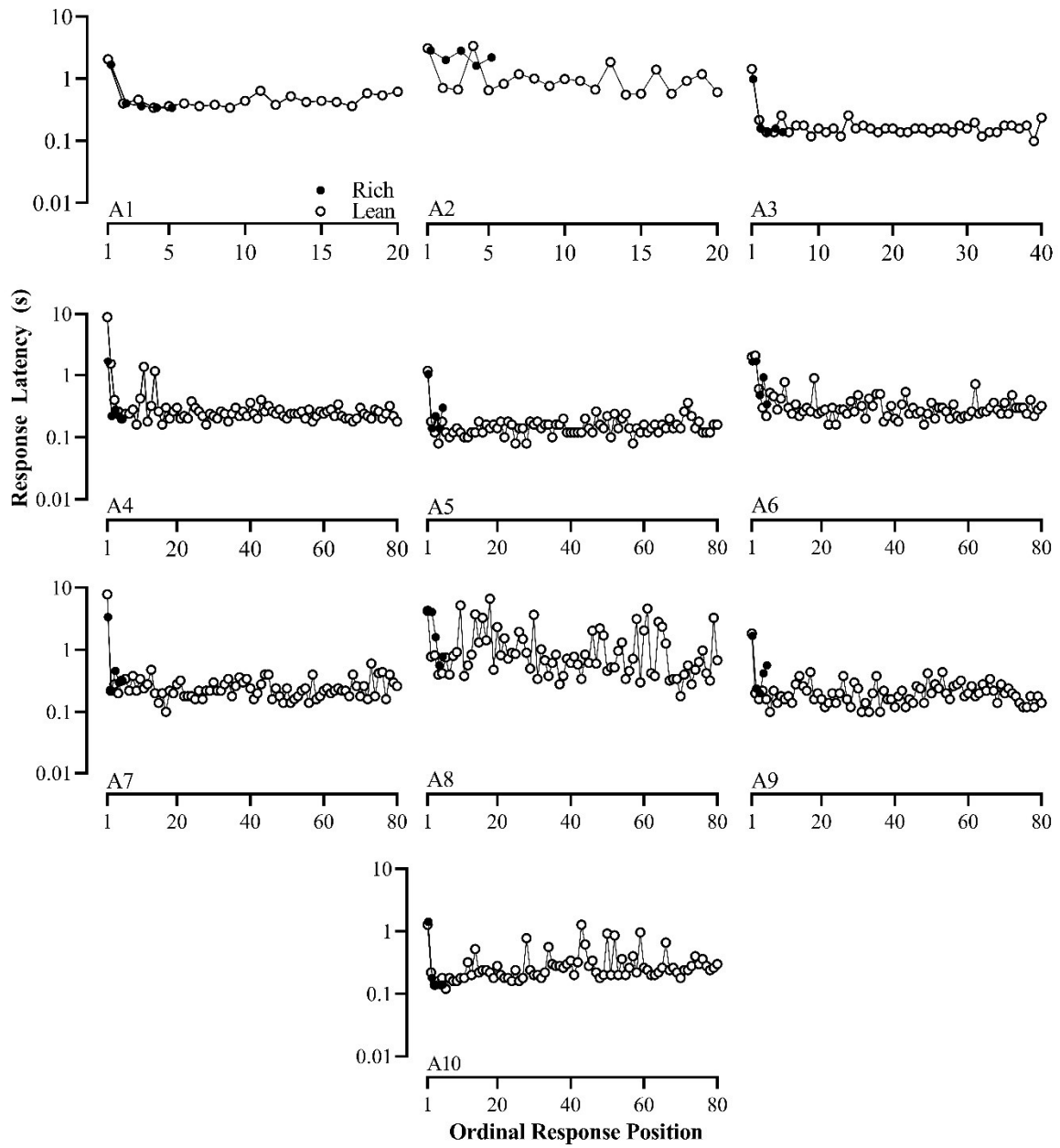
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**Figure 1**

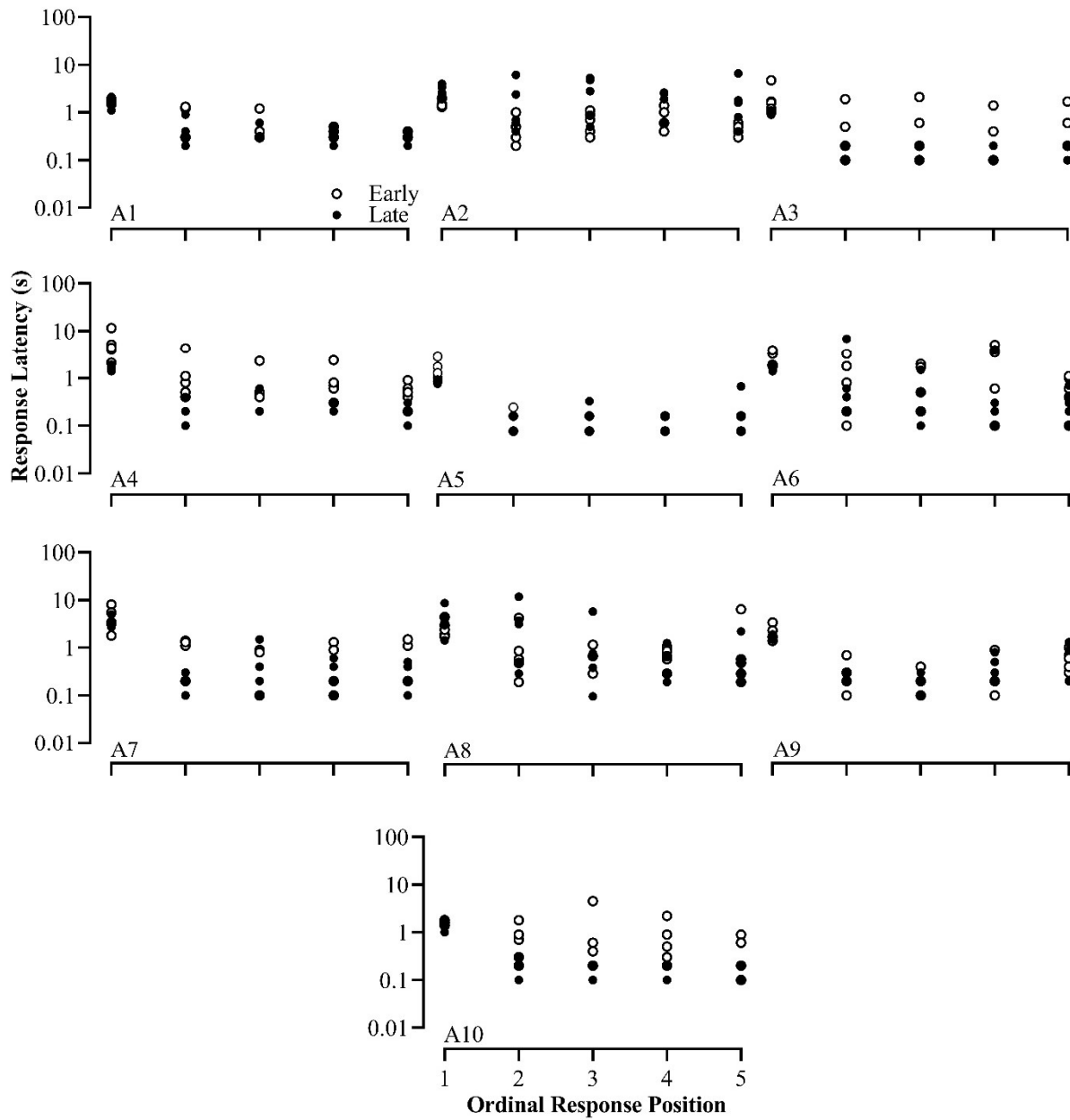
*Response latencies (PRP and IRT) by Ordinal Response Position*



Notes: Values are a mean of last five schedule completions. First latency is PRP.

**Figure 2**

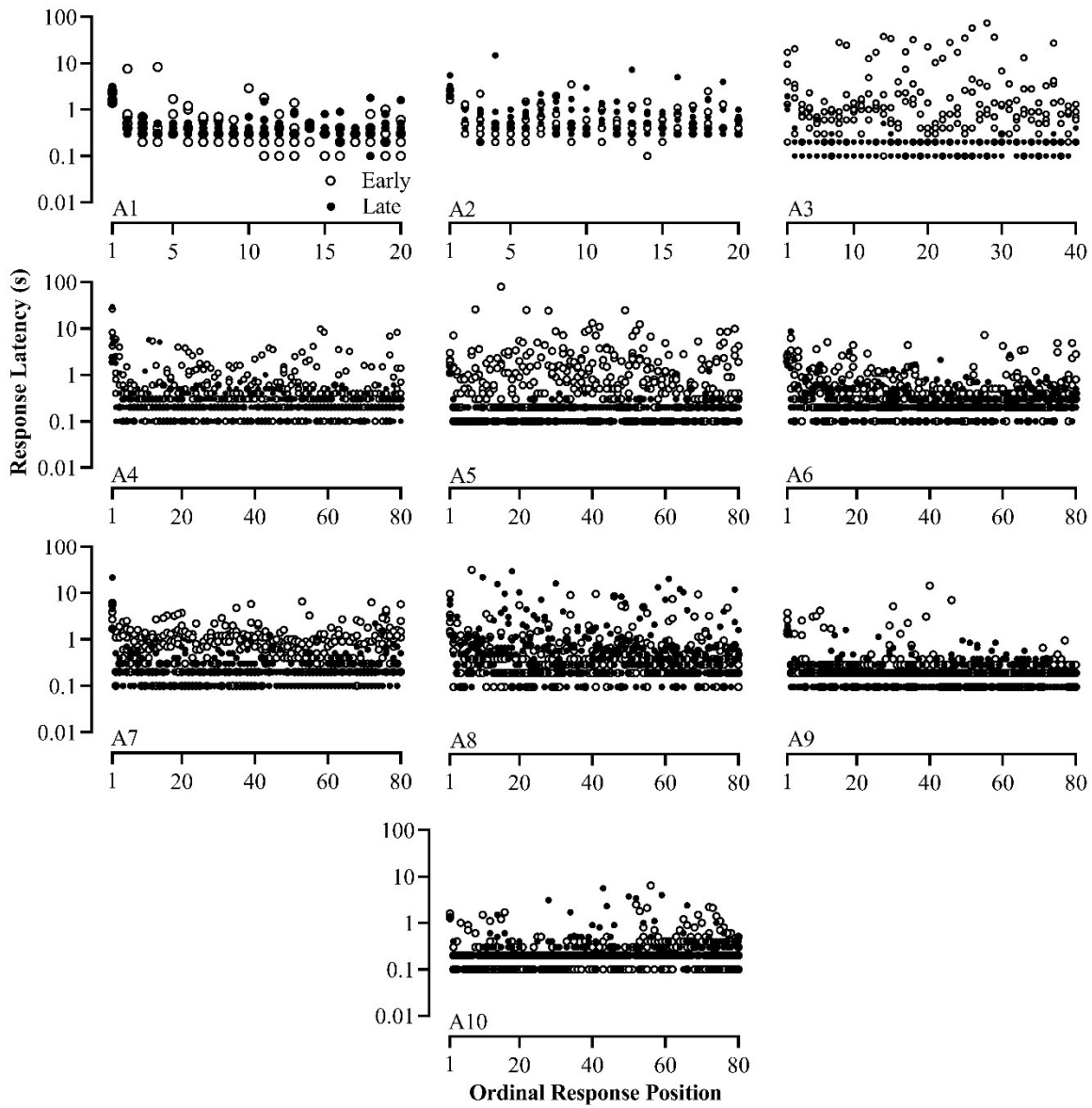
*Comparison of FR 5 Response Latencies Early and Late in Session*



Note: Values from the first five (early) and last five (late) schedule completions of the session.

**Figure 3**

*Comparison of FR 20, 40, and 80 Response Latencies Early and Late in Session*

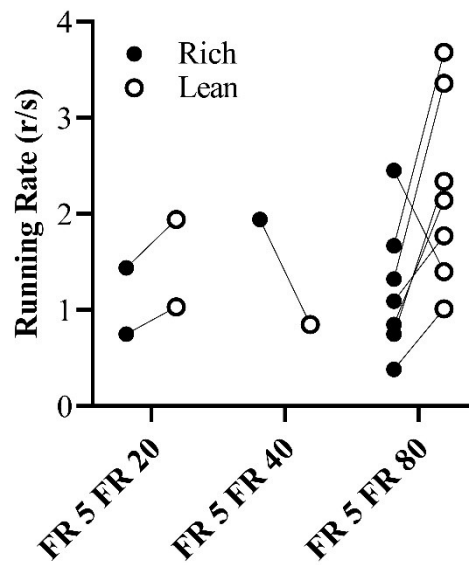


Notes: Details same as Figure 2.



**Figure 4**

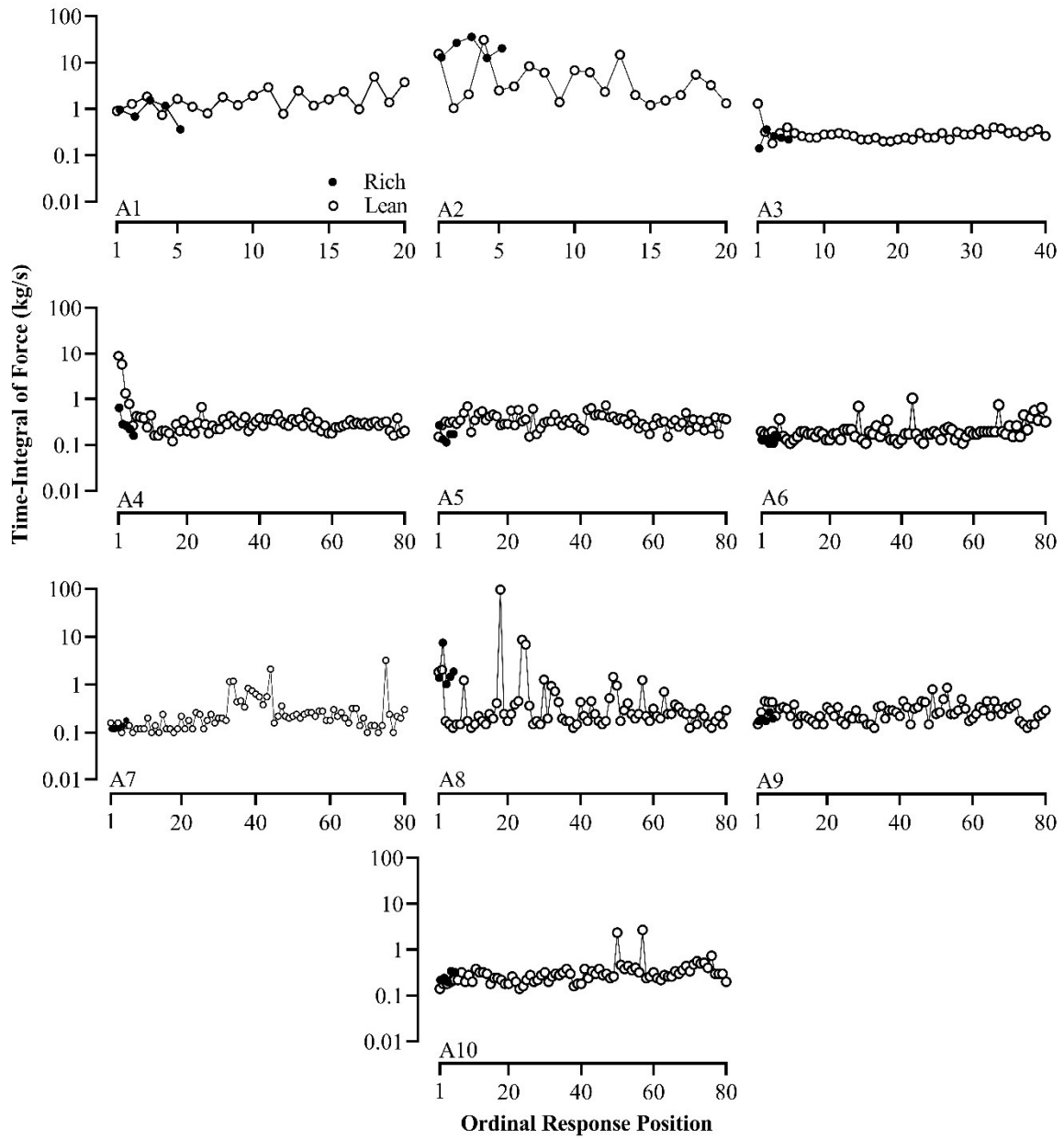
*Running Rate during Rich and Lean Components*



Notes: Each dyad shows mean running rate during rich and lean components for an individual participant.

**Figure 5**

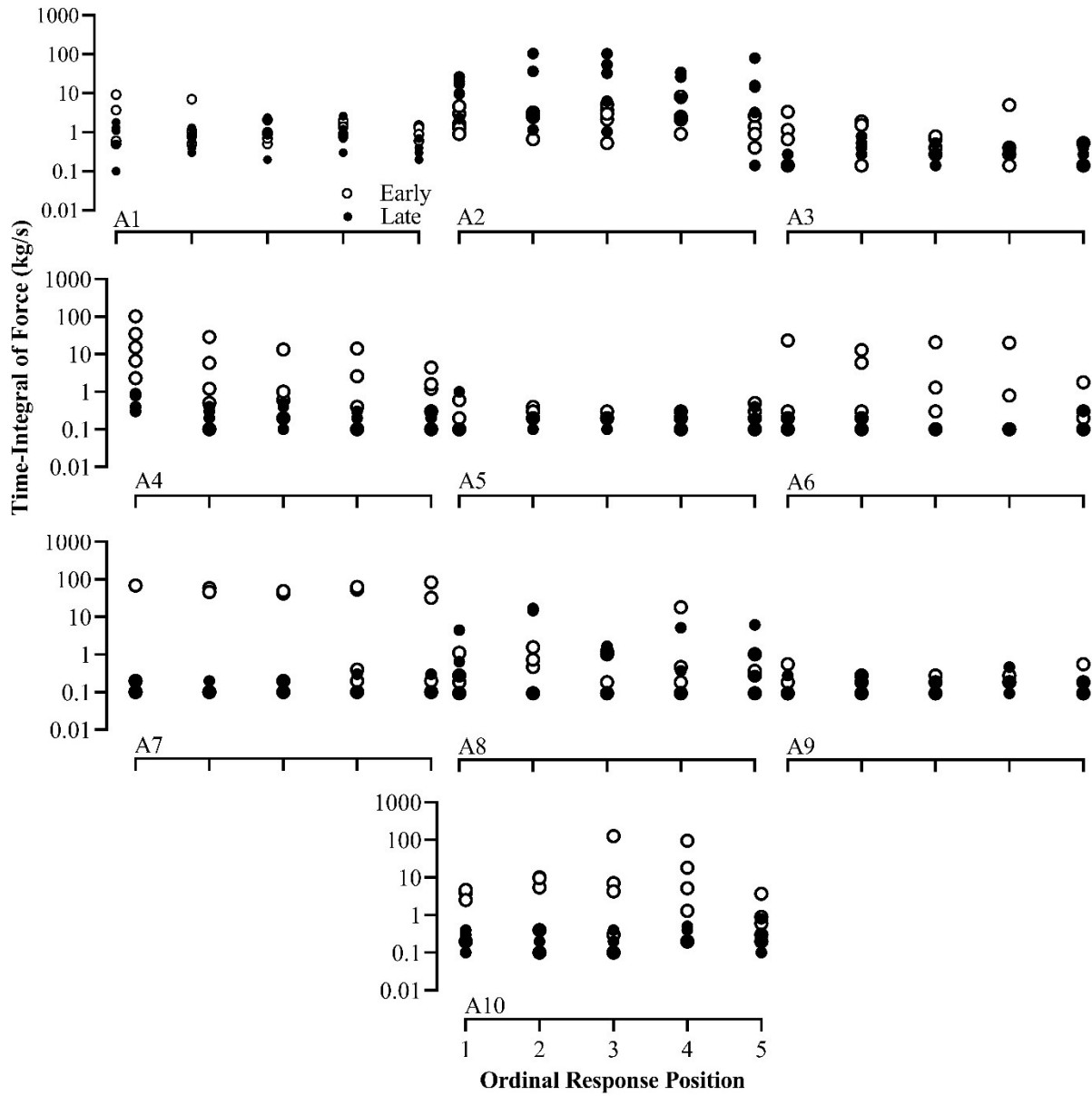
*Time-Integral of Force by Ordinal Response Position*



Notes: Values are a mean of last five schedule completions.

**Figure 6**

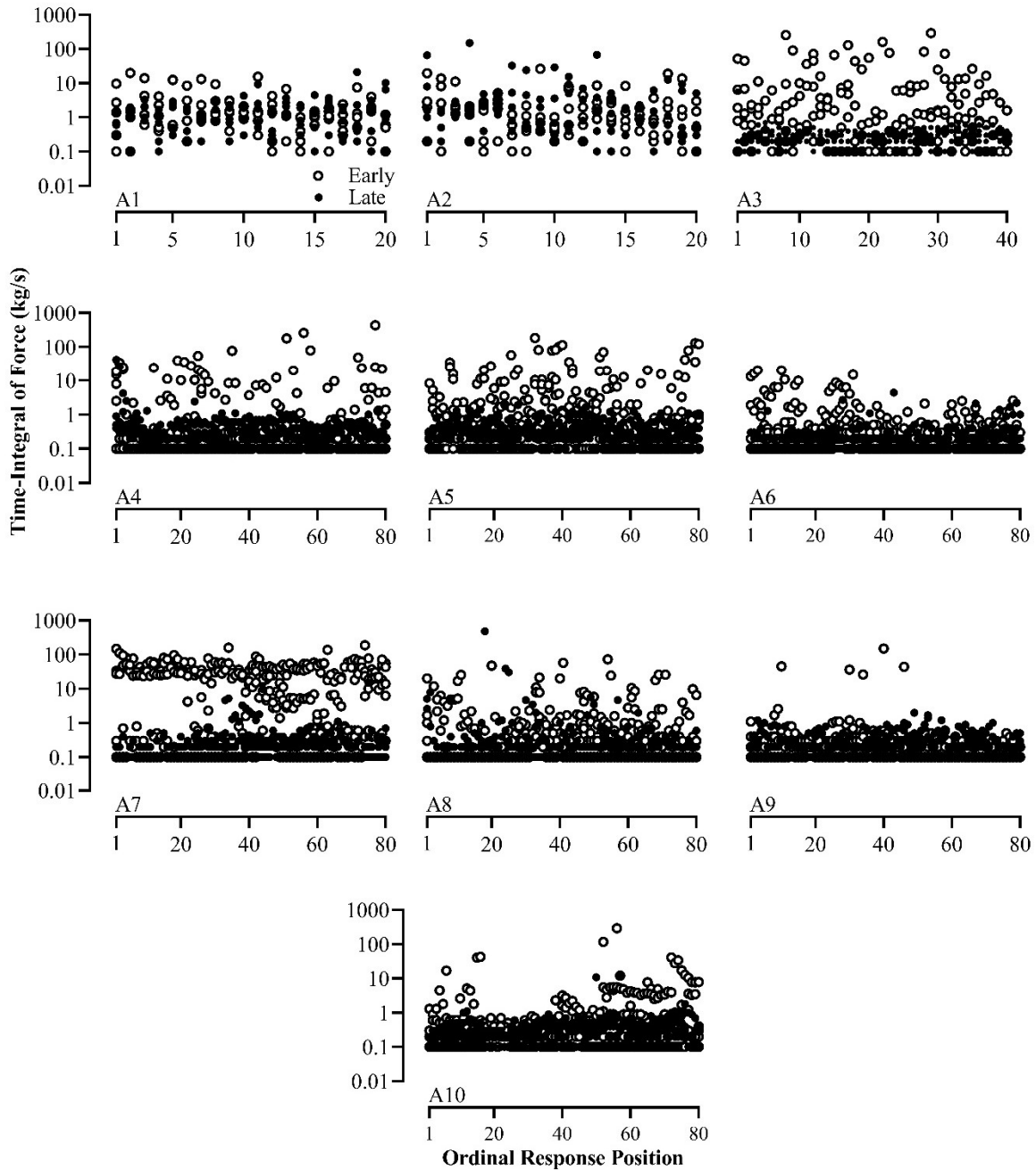
*Comparison of FR 5 Time-Integral of Force Values Early and Late in Session*



Notes: Values from the first five (early) and last five (late) schedule completions of the session.

**Figure 7**

*Comparison of FR 20, 40, and 80 Time-Integral of Force Values Early and Late in Session*



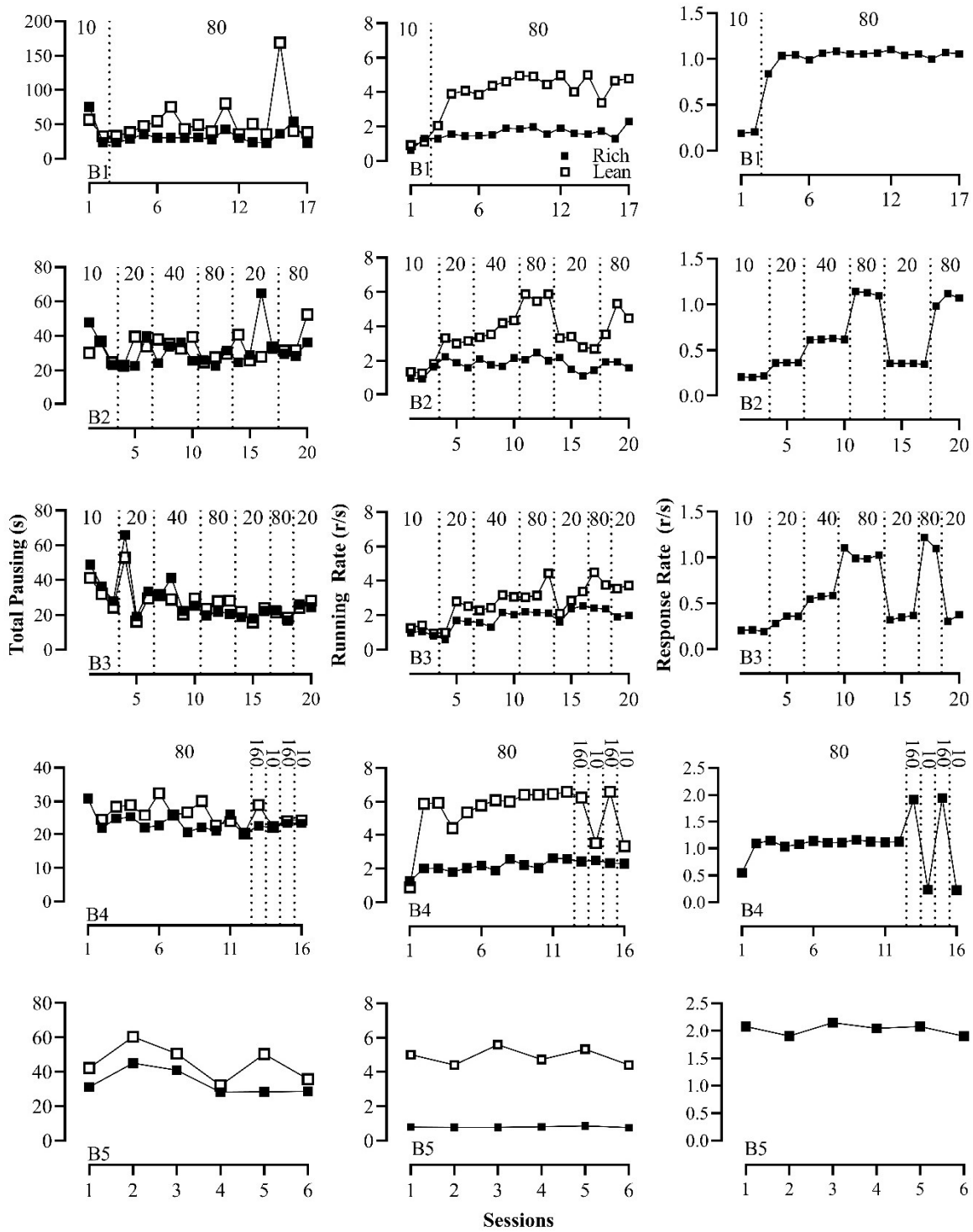
Notes: Details same as Figure 6.

**Table 1***Sequence of Conditions for Experiment Two*

| Participant | Ratio        | Sessions |
|-------------|--------------|----------|
| B1          | FR 5 FR 10   | 2        |
|             | FR 5 FR 80   | 15       |
| B2          | FR 5 FR 10   | 3        |
|             | FR 5 FR 20   | 3        |
|             | FR 5 FR 40   | 4        |
|             | FR 5 FR 80   | 3        |
|             | FR 5 FR 20   | 4        |
|             | FR 5 FR 80   | 3        |
| B3          | FR 5 FR 10   | 3        |
|             | FR 5 FR 20   | 3        |
|             | FR 5 FR 40   | 4        |
|             | FR 5 FR 80   | 3        |
|             | FR 5 FR 20   | 3        |
|             | FR 5 FR 80   | 2        |
|             | FR 5 FR 20   | 2        |
| B4          | FR 5 FR 80   | 12       |
|             | FR 5 FR 160  | 1        |
|             | FR 5 FR 10   | 1        |
|             | FR 5 FR 160  | 1        |
|             | FR 5 FR 10   | 1        |
| B5          | FR 16 FR 256 | 5        |

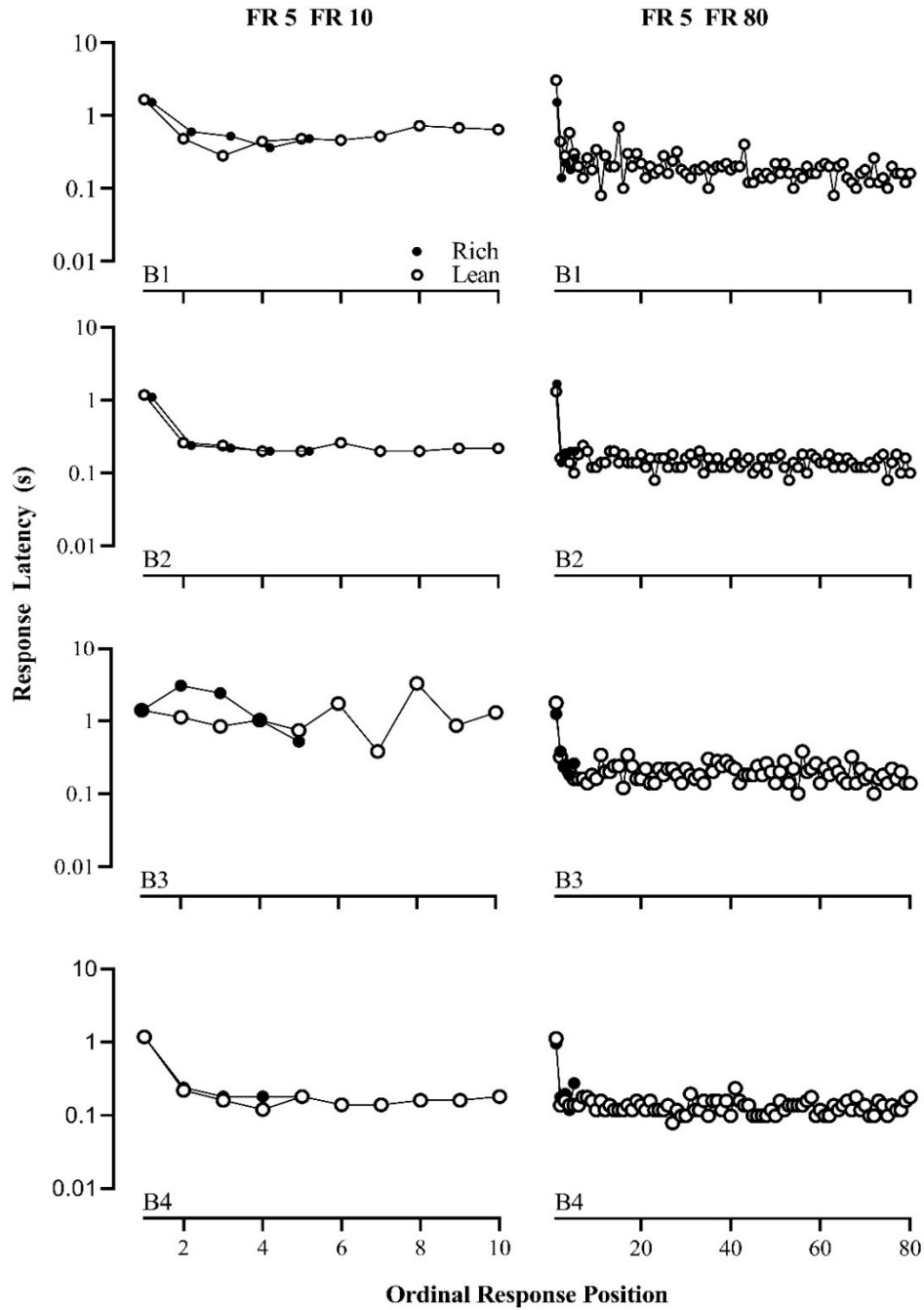
**Figure 8**

*Total Pausing, Running Rate, and Response Rate Across Sessions (Experiment 2)*



**Figure 9**

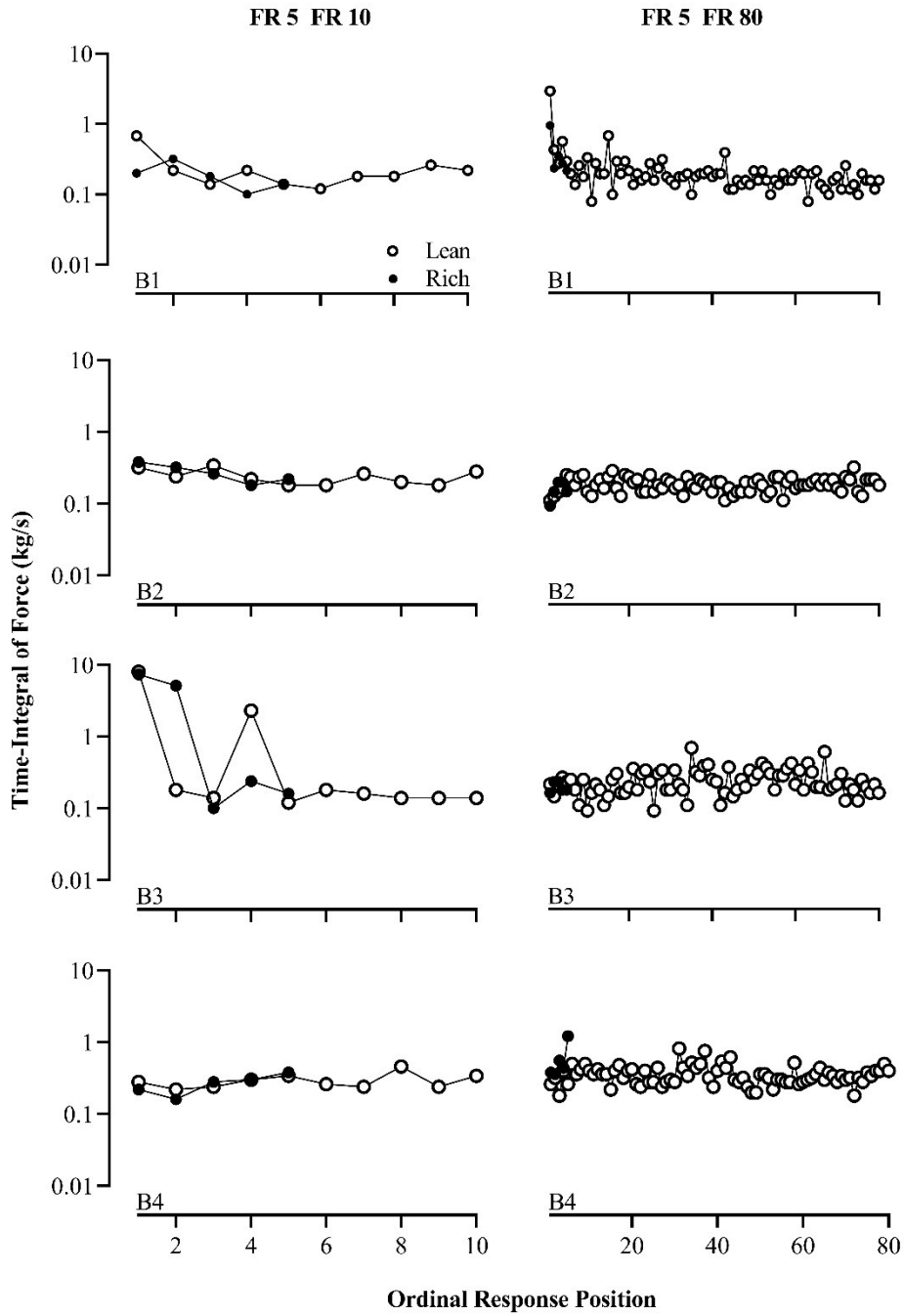
*Response latencies (PRP and IRT) by Ordinal Response Position*



Notes: Values are a mean of last five schedule completions for FR 5 FR 10 and FR 5 FR 5 FR 80 conditions. First latency is PRP.

**Figure 10**

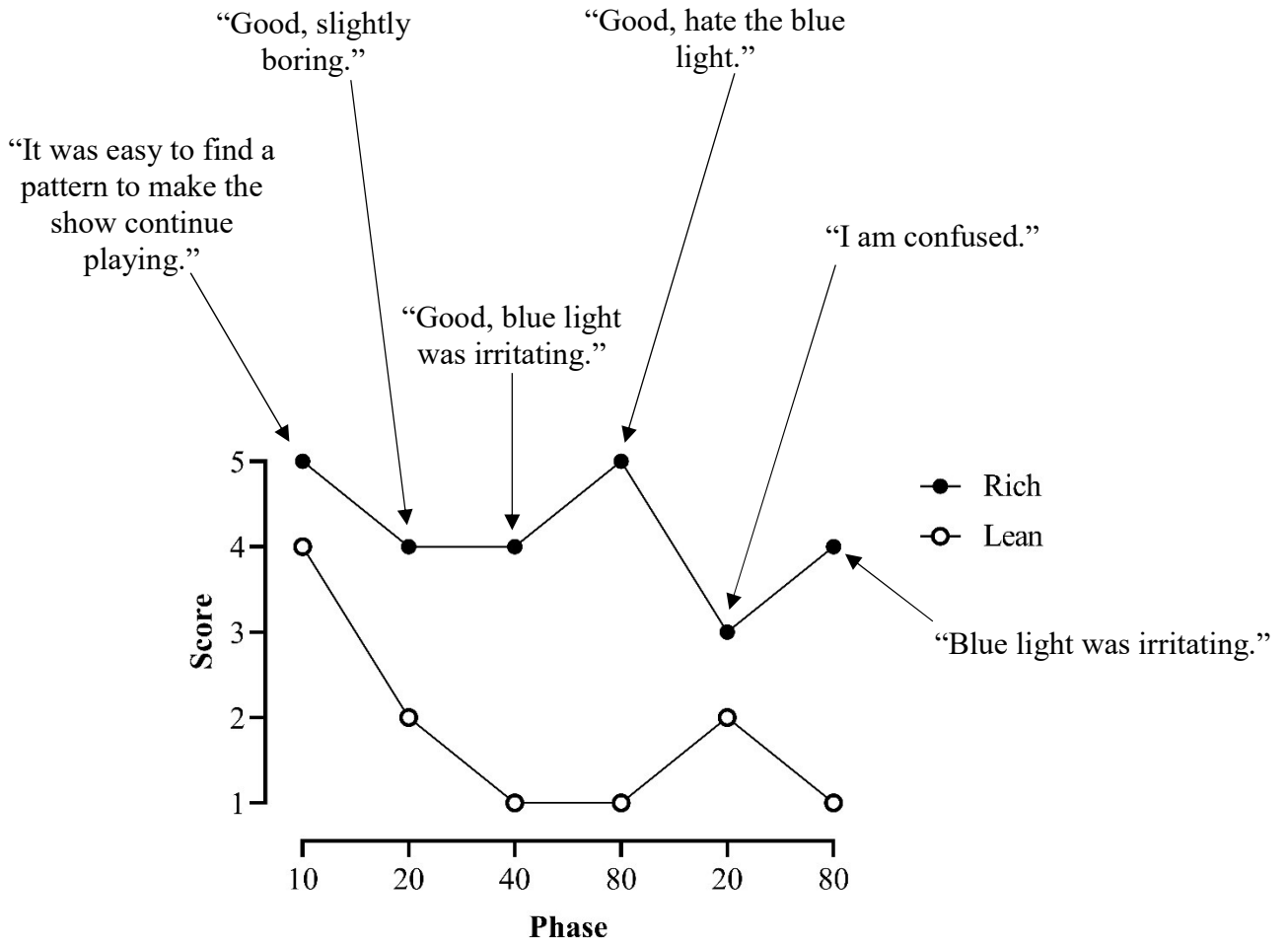
*Time-Integral of Force by Ordinal Response Position*





**Figure 11**

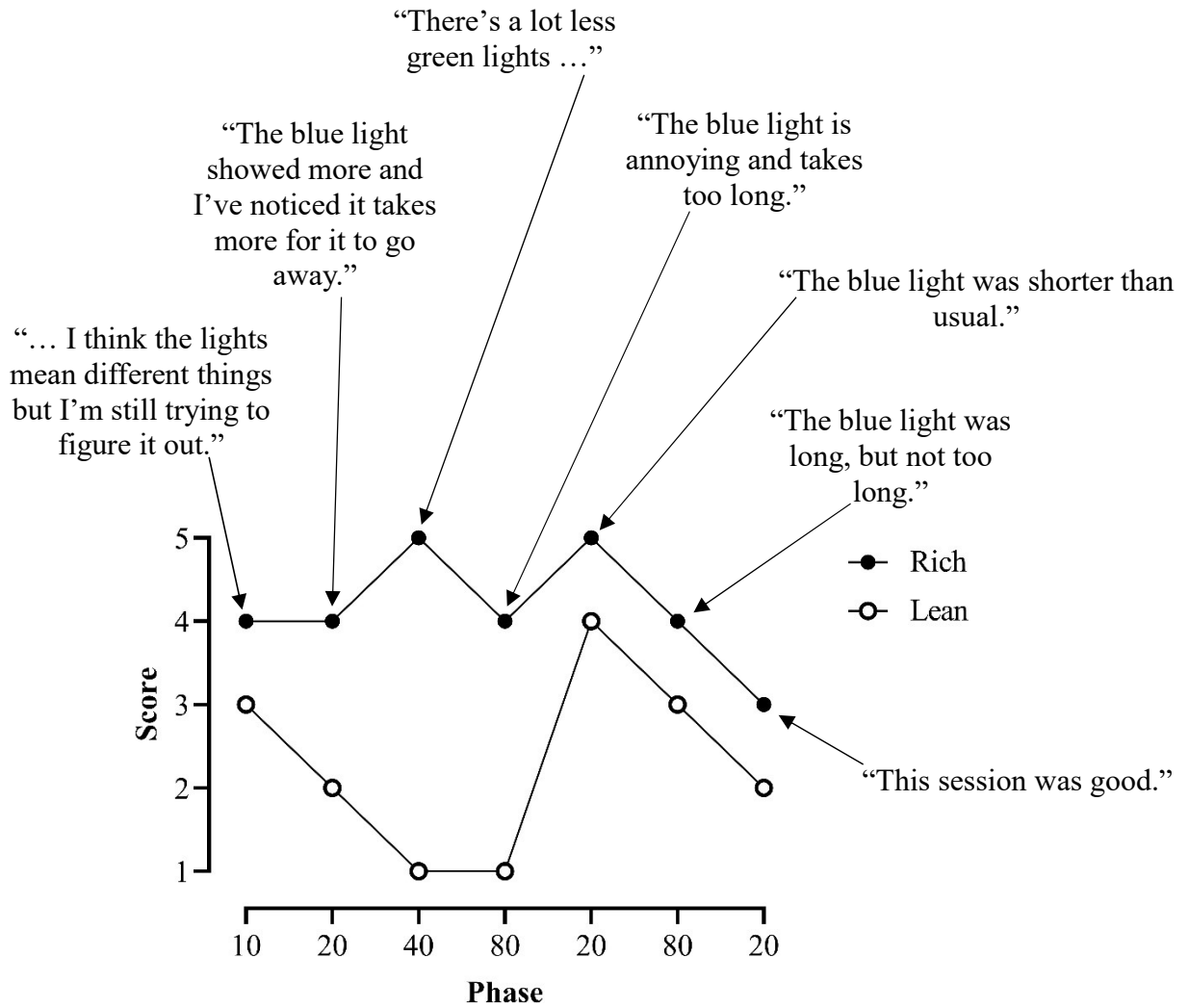
*Likert-Type Rating of Component-Correlated Stimuli and Verbal Behavior Across Phases for B2*



Notes: Likert-type Scale: 5 = Strongly liked, 4 = liked, 3 = neutral, 2 = disliked, 1 = strongly disliked.

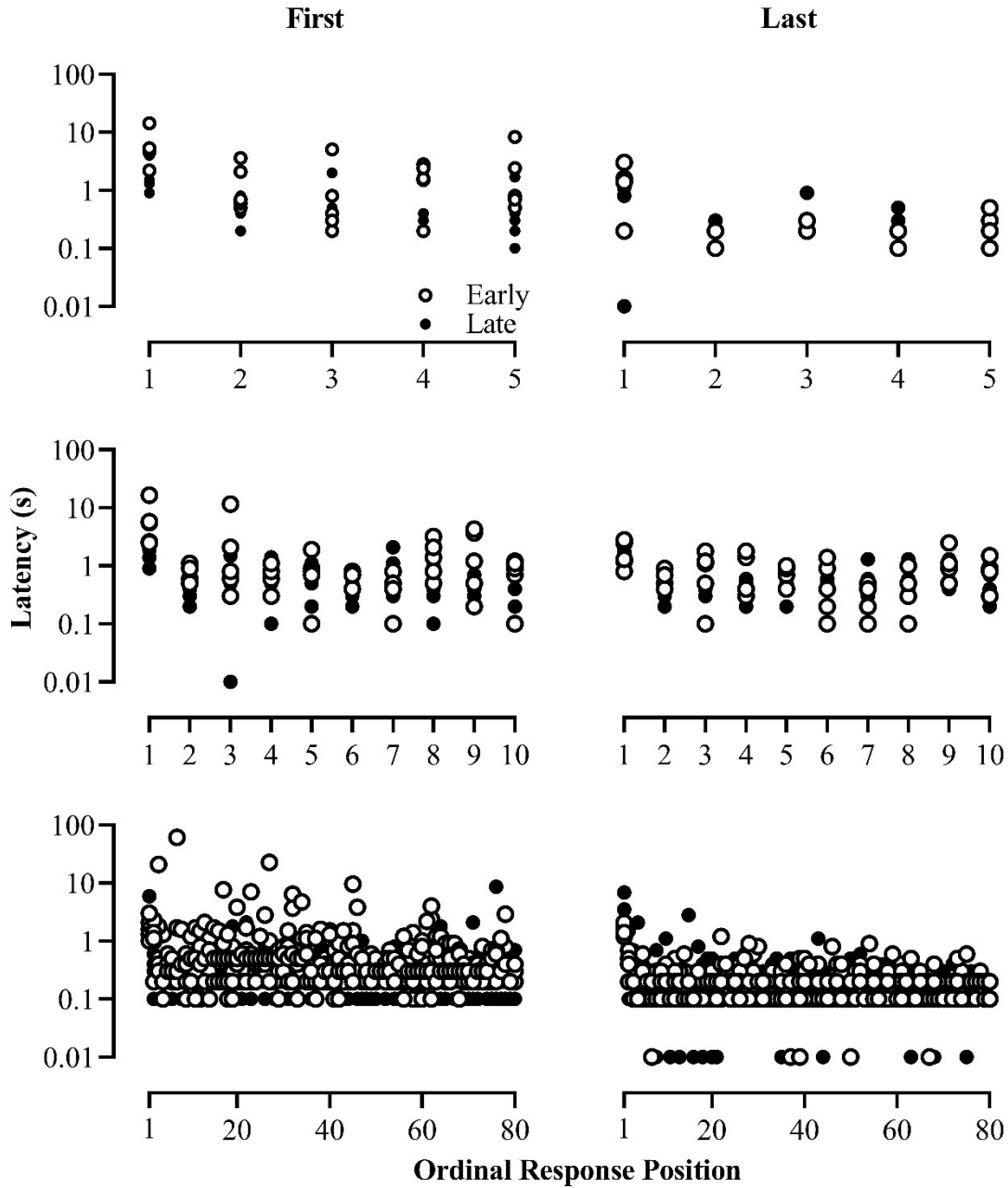
**Figure 12**

*Likert-Type Rating of Component-Correlated Stimuli and Verbal Behavior Across Phases for B3*



**Figure 13**

*Latencies Early and Late During the First and Last Session of Each Ratio Requirement for B1*

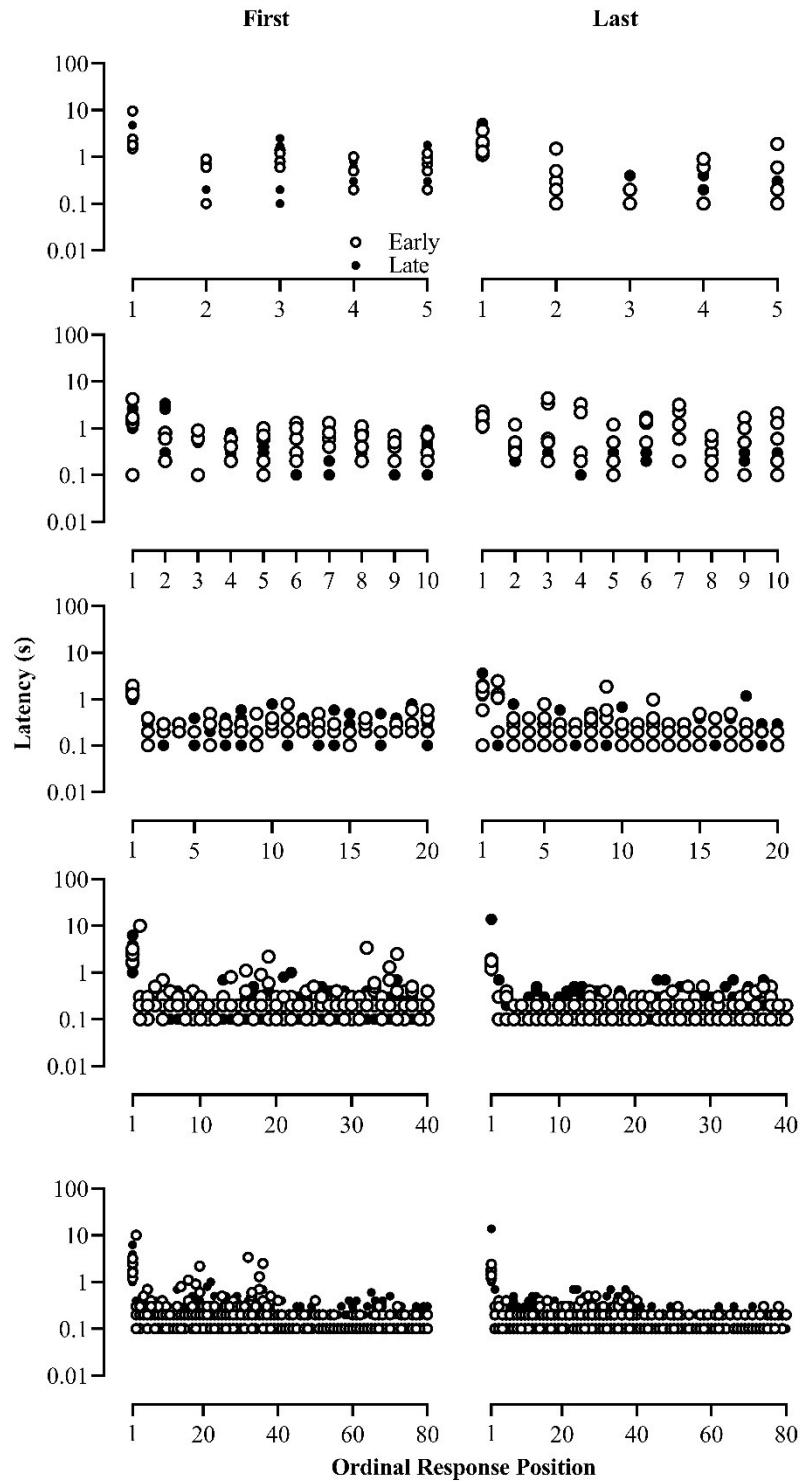


Notes: Open and closed circles show first and last five schedule completions of each session, respectively.

Left and right columns show the first and last session at a particular ratio requirement.

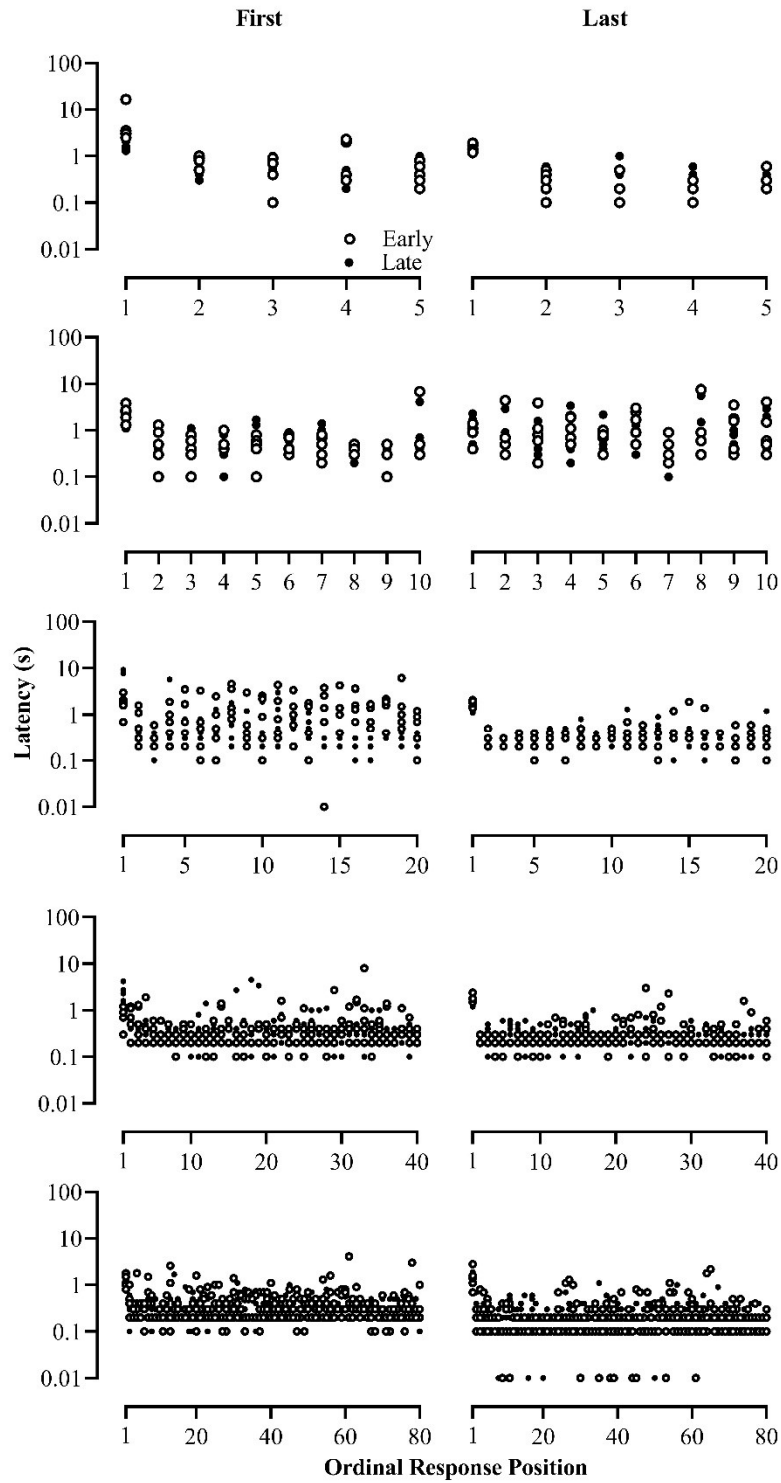
**Figure 14**

*Latencies Early and Late During the First and Last Session of Each Ratio Requirement for B2*



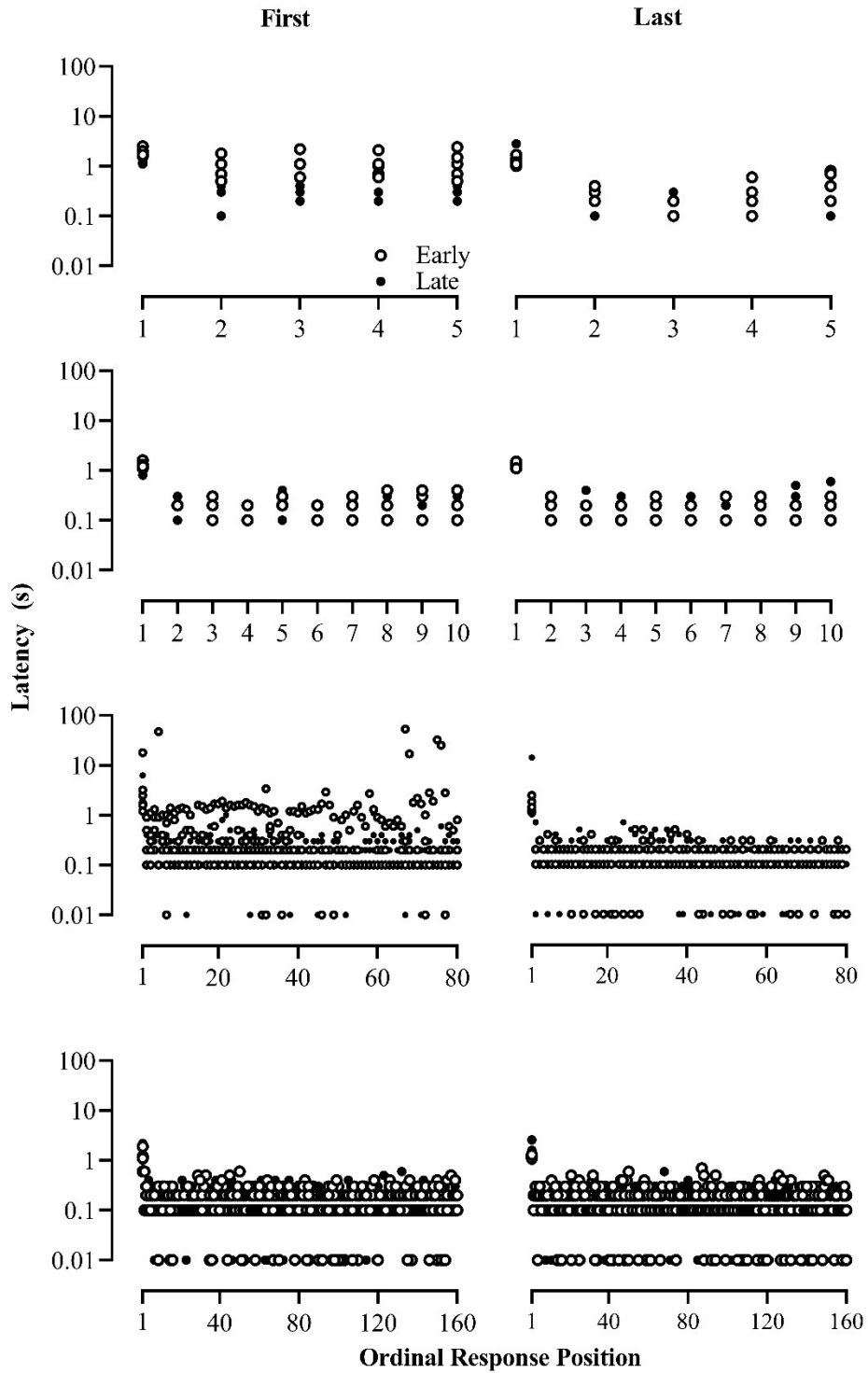
**Figure 15**

*Latencies Early and Late During the First and Last Session of Each Ratio Requirement for B3*



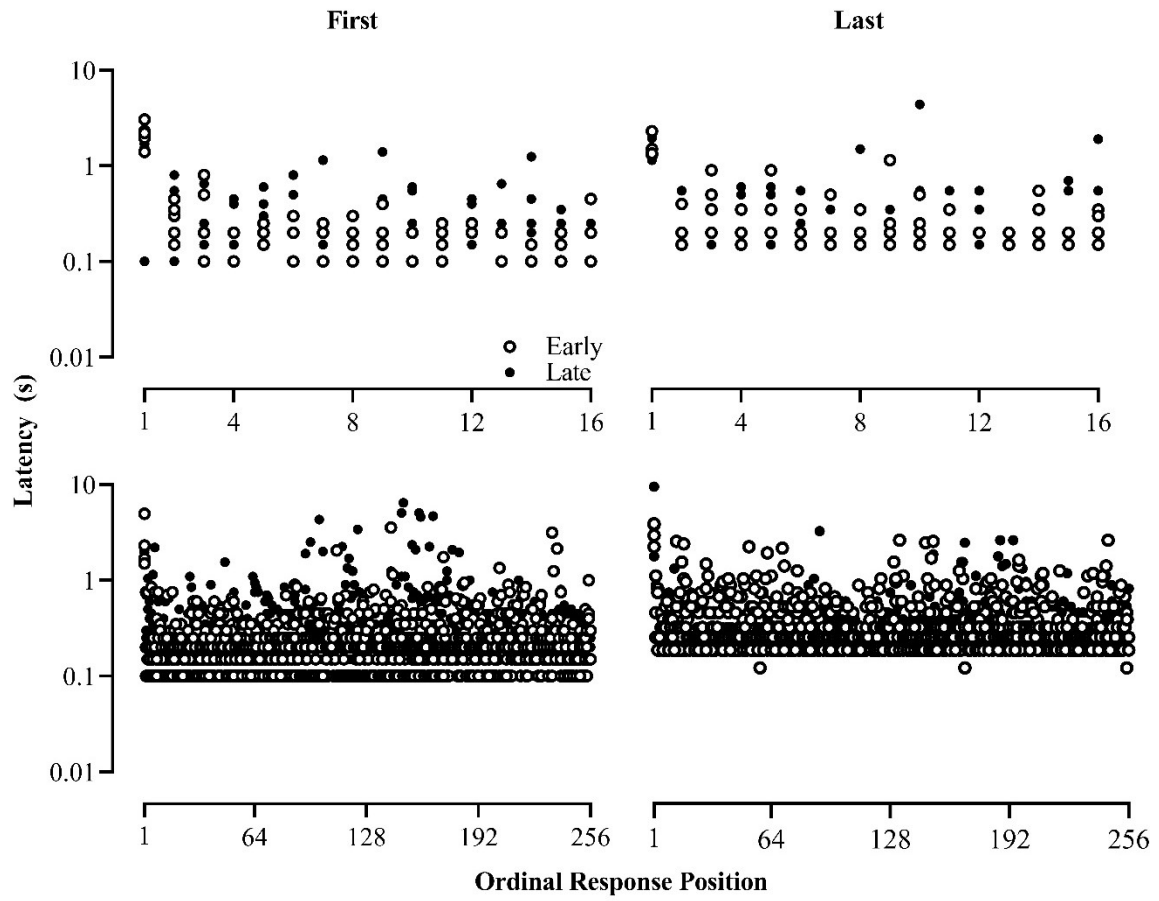
**Figure 16**

*Latencies Early and Late During the First and Last Session of Each Ratio Requirement for B4*



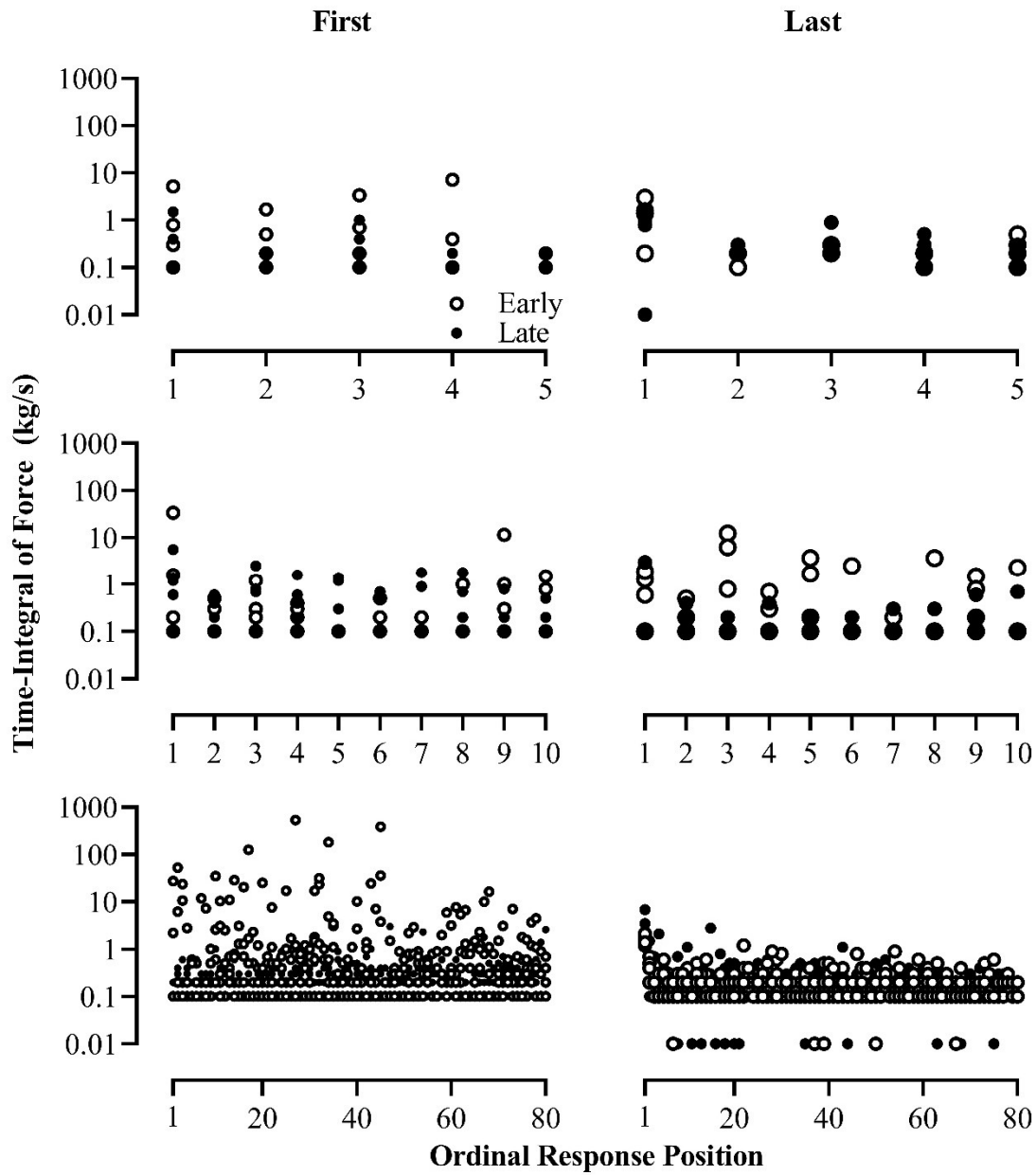
**Figure 17**

*Latencies Early and Late During the First and Last Session of Each Ratio Requirement for B5*



**Figure 18**

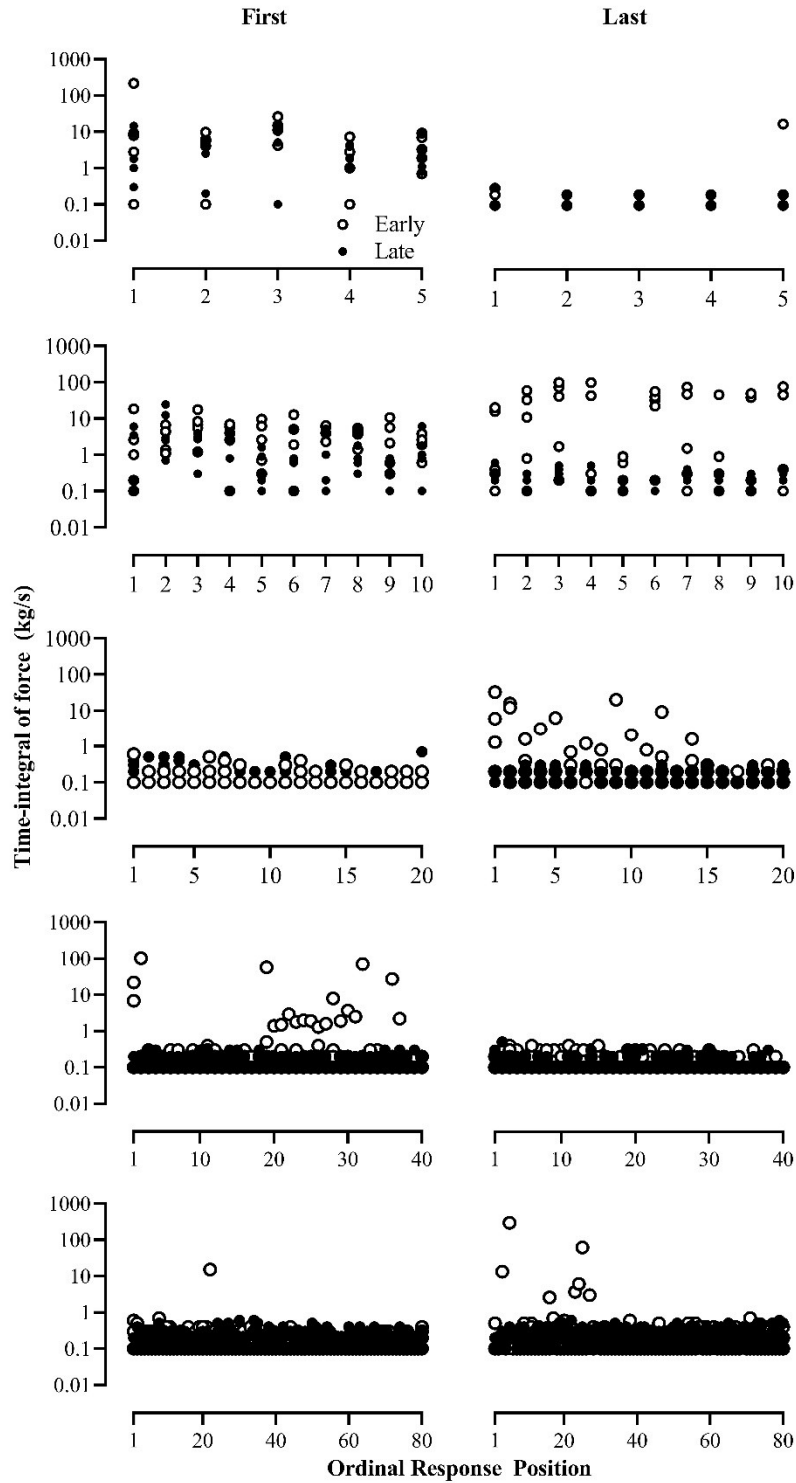
*Response Force Early and Late During the First and Last Session of Each Ratio Requirement for B1*





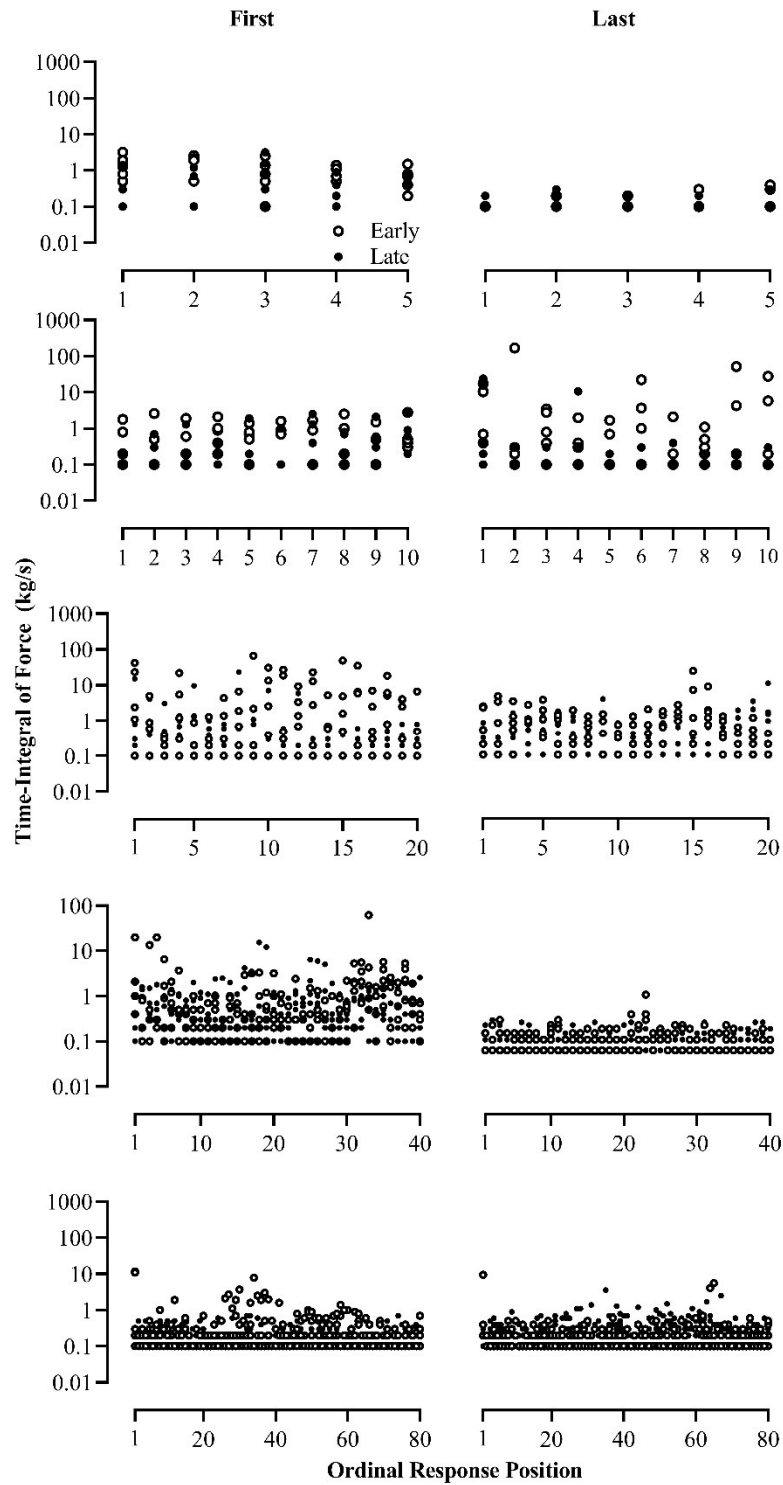
**Figure 19**

*Response Force Early and Late During the First and Last Session of Each Ratio Requirement for B2*



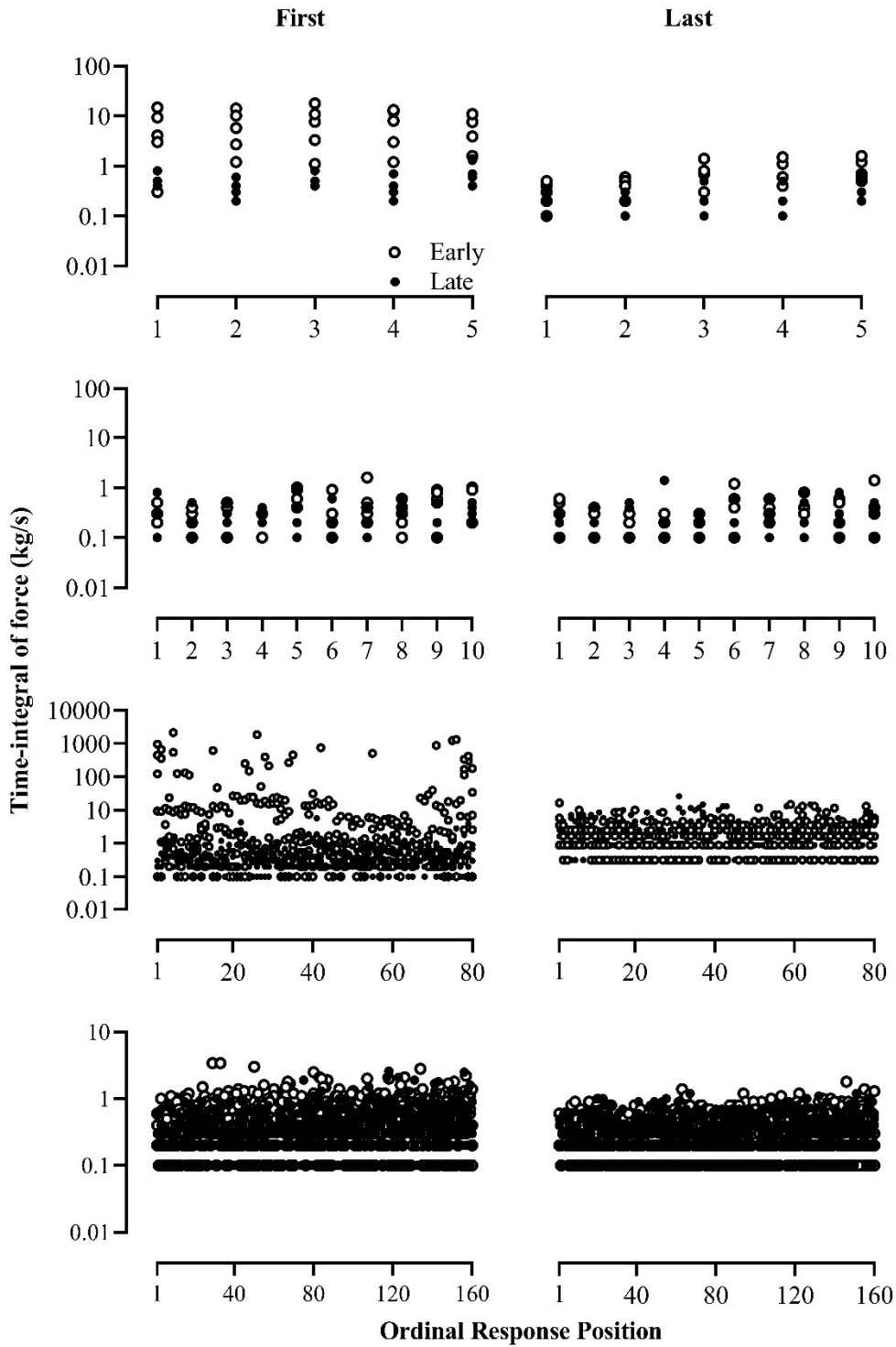
**Figure 20**

*Response Force Early and Late During the First and Last Session of Each Ratio Requirement for B3*



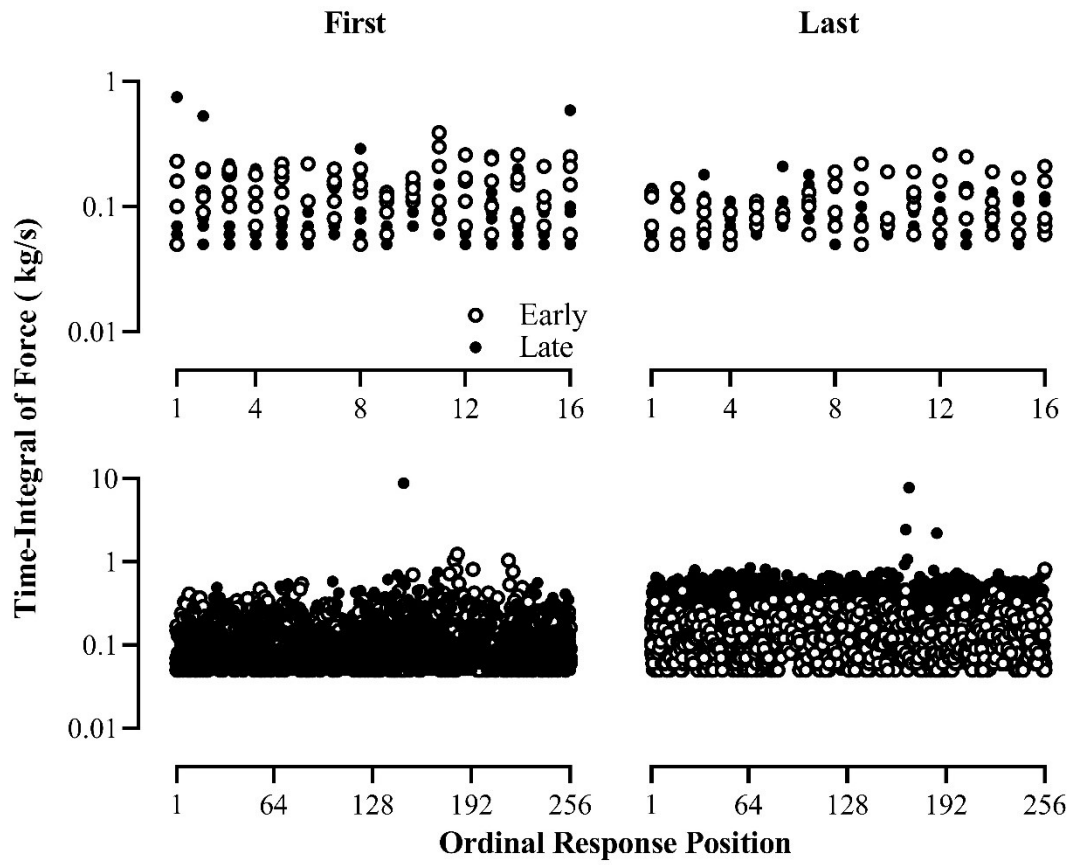
**Figure 21**

*Response Force Early and Late During the First and Last Session of Each Ratio Requirement for B4*



**Figure 22**

*Response Force Early and Late During the First and Last Session of Each Ratio Requirement for B5*



**Appendix A***Post-Session Survey*

Name: \_\_\_\_\_

Date: \_\_\_\_\_

## Post-session survey

1) How did you feel about the green light today?

|                  |         |         |      |               |
|------------------|---------|---------|------|---------------|
| Strongly Dislike | Dislike | Neutral | Like | Strongly Like |
| 1                | 2       | 3       | 4    | 5             |

2) How did you feel about the blue light today?

|                  |         |         |      |               |
|------------------|---------|---------|------|---------------|
| Strongly Dislike | Dislike | Neutral | Like | Strongly Like |
| 1                | 2       | 3       | 4    | 5             |

How did you feel about this past session?

Do you have any theories or ideas that you'd like to share about the goal of the study?