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Human performance on random interval schedules

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Abstract

Four experiments explored the factors controlling human responding on random interval (RI) schedules of reinforcement. All experiments identified two types of responding: ‘bout-initiation’ and ‘within-bout’ responding. Responding on RI schedules was related to the interval value – rates being higher on an RI-30s than on an RI-60s or RI-120s schedule, and this impacting bout-initiation responding to the greater degree (Experiments 1 and 3). Experiment 2 found similar overall response rates on random ratio (RR) and random interval with a linear feedback loop (RI+) schedules, with both higher than on an RI schedule. Bout-initiation rates were similar across all schedules, but within-bout responding differed. Experiments 3 and 4 examined the impact of a response cost, and noted greater bout-initiation responding but not greater within-bout rates with low costs. Overall, these experiments suggest that bout-initiation responding may be subject to control by factors that increase the strength of conditioning to the context, whereas within-bout responding is less sensitive to these influences.

Key words: random interval, schedule, bout initiation, within bout responding, schedules of reinforcement, humans.

Recent effort has been devoted to examining whether free-operant responding (Ferster & Skinner, 1957; Lattal, 2012) is composed of different types of responses, and whether different response-types are controlled by different aspects of the contingency (see Shull, 2011, for an overview). Such analyses have revealed that two distinct types of responses are emitted during exposure to free-operant schedules: ‘bout-initiation’ responses that start a bout of responding; and ‘within-bout’ responses, emitted during a bout of responding (Bowers, Hill, & Palya, 2008; Brackney, Cheung, Neisewander, & Sanabria, 2011; Killeen, Hall, Reilly, & Kettle, 2002; Reed, 2011; Shull, 2011; Shull, Gaynor, & Grimes, 2001; Sibley, Nott, & Fletcher, 1990).

Bout-initiation responding appears related to overall rates of reinforcement and deprivation levels (Killeen et al., 2002; Shull et al., 2001; Shull, 2011). In contrast, within-bout responses appear controlled by factors, such as inter-response time (IRT) reinforcement (Brackney et al, 2011; Shull, 2011; Shull et al., 2001). Gaining information regarding factors controlling the ‘micro-structure’ of responding may further theoretical understanding of free-operant performance. Currently available results suggest that ‘molar’ level factors (requiring integration across time) may impact bout-initiation responding, but that ‘molecular’ level factors control within-bout responding.

However, a hindrance to theory development is the limited range of manipulations conducted to explore factors determining such performance. For example, there is very limited data on the extent to which the molar feedback function relating response rate to reinforcement, or punishment contingencies, affect bout-initiation and within-bout responding. In fact, an alternative conceptualization of these data to the above molar/molecular division is that factors impacting the strength of Pavlovian conditioning of the context (e.g., rate of reinforcement and punishment) will affect bout-initiation responses. Factors not affecting this aspect (e.g., IRT reinforcement, response-reinforcer feedback function) may impact within-bout responding, as they would neither add nor subtract to the level of reinforcement experienced in that context (see Reed, 2015c). The current series of experiments was designed to extend the range of factors that have been explored with regard to their impact on the micro-structure of free-operant performance with a view to informing the development of theory.

The factors controlling bout-initiation and within-bout responses have been studied using log survival plots of IRTs (see Brackney et al., 2011; Killeen et al., 2002; Shull et al. 2001). A frequency distribution for the emitted IRTs is created, and the percentage calculated of IRTs emitted in a particular time bin as a proportion of all IRTs that had not yet been emitted when that time bin started (i.e. those that fall into that and the later time bins). These survivor percentages are then turned into logs, and a ‘log survivor plot’ is generated from these data (Shull, 2011; Shull et al., 2001). In a log survivor plot, the slope between any two points is an indicator of the relative decline in the proportion of the IRTs per opportunity between those points and indicates response rate: the steeper the slope, the higher the relative rate of responding during the interval.

Figure 1 about here

Shull et al. (2001; see also Brackney et al., 2011; Killeen et al., 2002; Sibley et al., 1990) found that the slope of log survival plots for rats performing on free-operant schedules of reinforcement was not uniform, but rather comprised an initially negative slope, followed by a portion with a shallow negative slope (termed a ‘broken-stick’ appearance; see Figure 1 for an idealized representation). This pattern of data was interpreted as indicating the presence of two different types of responding: a set of shorter IRTs prior to the break point (i.e., the point at which the slope of the line changes) reflecting ‘within-bout’ responding; and a set of longer IRTs following the ‘break’ point classed as ‘bout-initiation’ responses.

Although there is relatively good evidence regarding the micro-structure of nonhuman responding on free-operant schedules (see Shull, 2011), there is virtually no information regarding these effects in humans. The current series of studies also aimed to address this issue. The lack of evidence hinders the integration of theory derived from the study of nonhumans with the results of experiments conducted with humans, and has retarded the development of theories about the factors which control human instrumental performance. Reed (2015b) explored human random ratio (RR) performance (a schedule on which each response has the same probability of reinforcement as every other response), and determined that there did appear to be two distinct types of responses that were controlled by different aspects of the contingency. In this study, human bout-initiations were related to the rate of reinforcement, whereas within-bout responses tended to vary according to the ratio value. However, it should be noted that very few studies of nonhumans have employed such ratio schedules, and instead these experiments tend to use interval schedules (e.g., Brackney et al., 2011; Shull, 2011).

To further understanding of the nature of schedule-controlled human behavior, and to relate it more strongly to the data and theory derived from nonhumans, the current series of experiments focused on exploring the determinants of the ‘micro-structure’ of human performance on random interval (RI) schedules. It might be noted that much previous work with nonhumans has employed variable interval (VI) schedules (Shull, 2001). These VI schedules differ from RI schedules in that they employ a series of predetermined interval values, rather than assigning probabilities for a response in each second being reinforced, as with the RI schedule. There are some differences produced by these schedules, although studies using RI schedules in respect to the impact on the micro-structure of rat responding (e.g., Reed, 2011), have not noted differences relative to the factors that impact VI schedule performance.

Performance on interval schedules for nonhumans, typically, is related to the rate at which reinforcement is presented (Baum, 1973; Davison & McCarthy, 1988; deVilliers, 1977; Herrnstein, 1970). However, there is some debate regarding the degree to which human performance is also sensitive to variation in the reinforcement rate produced by interval schedules (cf. Bradshaw, Szabadi, & Bevan, 1976; Leander, Lippman, & Meyer, 1968; Lowe & Horne, 1985). The current experiments investigated whether humans would show sensitivity to features of RI schedules when important procedural factors were controlled, such as giving minimal verbal instructions (Bradshaw & Reed, 2012), adopting concurrent tasks to suppress the formation of verbal rules (Reed, 2015b), introducing costs for responding to bring responding under greater control by the schedule (Raia, Shillingford, Miller, & Baier, 2000; Reed, 2001), and controlling for personality variation (e.g., Randell, Ranjith-Kumar, Gupta, & Reed, 2009; Reed, Frasquillo, Colkin, Liemann, & Colbert, 2001).

If such RI performance could be established in humans, then the impact of aspects of the schedule, such as rates of reinforcement, and response-reinforcement feedback functions, on the different response types could be explored. In particular, it could be established whether human bout-initiation responses on RI schedules were controlled by rates of reinforcement, and whether within-bout responding would show any relationship to this factor (Bowers & Grimes, 2008; Reed, 2011; Shull et al., 2001). In addition, the experiments investigated the influence of a number of contingency factors thought to be important for maintaining human free-operant responding, such as the response-reinforcer feedback function (McDowel & Wixted, 1986; Reed, 2007), and the cost of response (see Raia et al., 2000; Reed, 2001), which have not previously received analysis in terms of their impacts on the micro-structure of schedule-controlled responding. The effects of these manipulations would be of particular interest, as they may shed light on the theoretical understanding of the control of bout-initiation and within-bout responding.

Experiment 1

Experiment 1 examined the manner in which three different RI schedules (RI-30s, RI-60s, and RI-120s) controlled the rate and structure of human free-operant performance. If human performance on RI schedules was similar to that noted in other species, then response rates should decrease as the interval value increases (e.g., Baum, 1973; Bradshaw et al., 1976; Davison & McCarthy, 1988; deVilliers, 1977). However, this study also aimed to explore the structure of human RI performance and sought to determine whether the two types of schedule controlled behavior (bout-initiation and within-bout responses) are impacted by different aspects of the RI schedule contingency in humans as they are for nonhumans: the rate of bout-initiation responses increases with shorter interval values, but the within-bout responses are not as sensitive to this manipulation (Brackney et al., 2011; Killeen et al., 2002; Shull et al., 2001). To explore this, the log survivor (Shull, 2011) method was used to analyze the data obtained from humans responding on a range of RI schedules. Additionally, procedures highlighted as important in previous studies were adopted to bring the human performance under greater schedule control; that is by using: a response cost (Raia et al., 2000; Reed, 2001), a verbal suppression task (Bradshaw & Reed, 2012), and screening for aberrant personality types (Randell et al., 2009).

Method

Participants

Twenty-four participants (8 males and 16 females), aged 18-28 years, were recruited. The participants received Psychology Department subject-pool credits for their time. The participant with the greatest number of points obtained by the end of the study did receive a £50 gift token. All participants had normal or corrected-to-normal vision, and were naïve to the experiment's purpose. As previous studies have shown individuals scoring highly in terms of depression and schizotypy show atypical patterns of schedule performance (see Dack et al., 2009; Randell et al., 2009), psychometric tests were employed to exclude participants with high scores on these dimensions (Reed, 2015b). Four participants were excluded on the basis of having high depression or schizotypy scores, leaving 20 participants in the study.

Apparatus

The experimental task was presented using Visual Basic (6.0) on a laptop computer with a 15.6-inch screen. The program presented an RI schedule (30s, 60s, or 120s) to the participants. On a particular schedule, each second had an equal probability of being assigned as the period after which reinforcement would be delivered for a response (i.e., 1/30, 1/60, or 1/120). Each participant began the experiment with 40 points, displayed in a box, under the word “points”, in the middle of the screen horizontally, approximately one third of the way from the bottom of the screen. A colored square (either blue, purple, or yellow), approximately 8cm wide x 3cm high, was displayed in the middle of the screen, approximately one third from the top of the screen. Reinforcement consisted of 60 points being added to the ‘points’ box. Each response subtracted 1 point from the ‘points’ box, which aimed to prevent a lack of performance regulation in humans that can occur when there is no cost for a response (Bradshaw & Reed, 2012).

Measures

Oxford Liverpool Inventory of Feelings and Experiences - Brief Version (O-LIFE(B); Mason, Linney, & Claridge, 2005) measures schizotypal traits along four dimensions, and has a Cronbach α between .62 and .80 (Mason et al., 2005). A score of greater than 6 on the Unusual Experiences scale was taken as a cut-off point for individuals displaying levels of this trait associated with atypical schedule performance (see Randell et al., 2009).

Beck’s Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) assesses depression, and has a Cronbach α between .73 and .92 (Beck, Steer, and Garbin, 1988). A score of higher than 10 was taken as a cut-off for depression that could produce atypical schedule performance (see Dack et al., 2009).

Procedure

Participants were tested individually in a quiet room containing a desk, a chair, and a computer. Participants read the written instructions, and then completed both scales. After this, the following instructions were presented on the computer screen:

“This experiment is concerned with multi-tasking abilities. You have two tasks to complete simultaneously. In the first task, you must count backwards, out-loud, in 7s, from the number 26,758. The second task is to score as many points as possible by pressing the space bar on the computer. The coloured shape may be important. To receive points, sometimes you might need to press the spacebar quickly and at other times you might need to press slowly. The person with the best score on both tasks will receive a £50 [name of company] token.”

The participants received these instructions as such instructions have been used in previous studies of human schedule performance, and have been shown to be effective for inducing schedule behavior in humans that resembles that in nonhumans (see Bradshaw & Reed, 2012; Reed, 2015b). After presentation of the instructions, each participant was exposed to all three schedule types (RI-30s, RI-60s, and RI-120s) – in a randomized order across participants. Each schedule was presented once to each participant, each schedule exposure lasted 10 min, and there was a 30s inter component interval. Each different schedule was signaled by the presence of the different colored rectangle on the screen. The particular colors used to signal the schedules were randomized. Each response subtracted one point from the ‘points’ box displayed on the screen (responding was possible even with a negative points total). This response cost procedure was adopted to make each response meaningful to the participant (see Bradshaw & Reed, 2012; Reed, 2001; 2015b). Reinforcement consisted of the addition of 60 points to the ‘points’ box.

During the time in which they were performing on the schedules, the participants had to perform the counting backwards task (see Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002). They were each given one random five-digit number at the start of the procedure (different for each participant), and were asked to count backwards from that number, out-loud, in 7s. This procedure was adopted in an attempt to minimize the potential role of verbal rule formation in influencing participants' performance on the schedule (see Bradshaw & Reed, 2012; Leander et al., 1968; Lowe, 1979; Raia et al., 2000). In order to enhance task adherence, a recording device was placed prominently on the desk in front of the participant, and they were told that their answers to the counting task would be analyzed and scored later.

Results and Discussion

Figure 2 about here

The responses emitted during the last 5 min of exposure to each of the three schedule types were analyzed, as they were taken to represent performance on each schedule that was relatively free of interference from the preceding schedule condition. This was thought to be a reasonable assumption given that previous explorations of human schedule performance has suggested that responding on exposure a novel condition becomes quite stable after relatively few reinforcers (Reed, 2015b) or few minutes exposure (Bradshaw & Reed, 2012). The overall response rates are shown in the left panel of Figure 2, and were highest for the RI-30s and lowest for the RI-120s schedule. A one-way, repeated-measures analysis of variance (ANOVA) conducted on these data, the effect size (and its 95% confidence limits) was computed, as well as the Bayes Factor and the probabilities of the supported hypothesis (null or alternate) being true given the obtained data, were calculated. The latter statistics were employed to determine whether any conclusions that depended on a null result for one group of rats were likely due to power issues. These analyses revealed a statistically significant effect of schedule condition, $F(2,38) = 25.56$, $p < .001$, $\eta^2_p = .574$ [*95% CI* = .330 - .692], *Bayes Factor* = .083, $p(H_1/D) = .923$. Paired t-tests adopting a Bonferroni correction (.05/3 = .017) revealed significant differences between the RI-30s and RI-120s conditions, $t(19) = 5.06$, $p < .001$, and between the RI-60s and RR-120s conditions, $t(19) = 3.57$, $p < .01$. These findings are consistent with patterns of responding seen in nonhumans for RI schedules (deVillier, 1977; Herrnstein, 1970), and suggest that, when appropriate procedures are implemented, humans exhibit sensitivity to RI schedules values (see also Bradshaw et al., 1976; Bradshaw & Reed, 2012; Raia et al., 2000).

A log survivor analysis was employed to examine the pattern of responding emitted in the last 5 min of each of the three different schedules. The IRT data were analyzed by temporal bin (100ms), and the number of responses in each bin was calculated. The number of responses emitted during a 100ms bin was turned into a percentage of the number of responses that were not already emitted in the preceding bins. These percentage data were transformed to logarithms, and log survivor plots for all three schedules of reinforcement were generated for each participant.

The mean data obtained from using this procedure are shown in the right panel of Figure 2, and reveal a reasonable approximation to those generated from the study of nonhumans (see Brackney et al., 2011; Killeen et al., 2002; Shull et al., 2001). There was a ‘broken stick’ appearance, and the slope of the post break points appeared steeper for the shorter RI schedules, suggesting higher bout-initiation rates.

Figure 3 about here

Figure 3 shows the log survivor plots for each schedule for individual participants. These data show almost all participants produced similar response patterns to one another, and these patterns matched the description of the mean log survivor plots (right panel Figure 2). These findings have been noted for nonhumans when using such individual subject analysis of performance on VI schedules (Brackney et al., 2011; Killeen et al., 2002; Shull et al., 2001). The similarity of the overall patterns of data also implies that there are few qualitative differences between the VI schedules studied in nonhumans and the currently employed RI schedules, and that any mean results are not the result of an artifact of pooling data from separate subgroups of participants.

To analyze these data, they were fitted to an equation described by Shull (2011): $P_{(IRT>t)} = (1-p_{(D)})e^{-wt} + p_{(D)}e^{-bt}$; where, $P_{(IRT>t)}$ represents the proportion of IRTs longer than t; $p_{(D)}$ indicates the proportion of all responses that are bout-initiations, 1-$p_{(D)}$ indicates the proportion of all responses that are within-bout; e represents the base of natural logarithms; w represents the within-bout response rate; b represents the bout-initiation rate (determined with respect to between-bout pause time); and t represents elapsed time since the last response (i.e., the bin values). The number of responses per response bout can be estimated by $1/p_{(D)}$. Thus, numerical estimates of the key components of response rate can be estimated by fitting this equation to the data for each subject, and employing the best fitting values of b (bout-initiation rate), and w (within-bout response rate).

Figure 4 about here

The top panel of Figure 4 displays (solid bars) the mean bout-initiation rates over the last 5 min of exposure to each schedule as determined by fitting the above equation to the data. Inspection of these data shows that bout-initiation rates were higher on the RI-30s than on either of the other two schedules. A one-way, repeated-measures ANOVA revealed a significant effect of schedule condition, $F(2,38) = 3.14$, $p < .05$, $\eta^2_p = .142$ [.000 - .391], *Bayes Factor* = .259, $p(H_1/D) = .794$. Paired t-tests adopting a Bonferroni correction (.05/3 = .017) revealed a significant difference between the RI-30s and RI-120s conditions, $t(19) = 2.36$, $p < .01$. Inspection of the bottom panel of Figure 4 reveals that within-bout response rates (diagonal bars) were similar across the three conditions, and a repeated-measures ANOVA revealed no statistically significance, $F(2,38) = 2.56$, $p > .10$, $\eta^2_p = .119$ [.000 - .292], *Bayes Factor* = 4.163, $p(H_o/D) = .806$.

This finding of greater bout-initiation rates in shorter RI schedules has been found in experiments exploring the impact of various schedule parameters on nonhuman ratio responding (Reed, 2015b), and also in numerous studies of nonhuman RI schedule performance (Brackney et al., 2011; Killeen et al., 2002; Shull et al., 2001). That the rates of within-bout response were not as clearly impacted by rates of reinforcement is also in line with findings from nonhumans (Shull, 2011; Shull et al., 2001), and, together with the above findings, suggests that the structure of human responding on RI schedules is similar to that of nonhumans.

Experiment 2

Experiment 2 extended the investigation to examine whether different response-reinforcer feedback functions would differentially impact bout-initiation and within-bout responses. To this end, performance on an RI schedule was compared to that on an RR schedule, and also to that on an RI schedule with a linear feedback loop (i.e., an RI+ schedule; McDowell & Wixted, 1986), all with matched rates of reinforcement. Previous work has suggested that RR schedules will generate higher overall rates of responding than an RI schedule, even with the same frequency of reinforcement (Peele et al., 1984; Zuriff, 1970). This effect has also been found with human participants (Bradshaw & Reed, 2012; Randell et al., 2009). However, in nonhumans, it has been noted that, while the overall response rate on RR schedule is higher than that of a reinforcement-rate matched RI schedule, this is due to differences in the within-bout rate of responding. In contrast, there is little difference in terms of the rates of bout-initiation responses on the RI compared to the RR schedule when the schedules are matched for rate of reinforcement (Reed, 2007; 2011). It has not been established whether this effect is also observed in humans. In humans, the RI+ schedule, which has the molar properties of an RR schedule, but the molecular characteristics of an RI schedule, tends to produce similar rates of response to an RR schedule (McDowell & Wixted, 1986; Reed, 2015b), and higher than those in an RI schedule matched for reinforcement rate (Reed, 2007). The impact of this schedule on the structure of responding is entirely unknown for any species, and the current study aimed to determine this for human participants. If it were the case that this manipulation impacted bout-initiation responding, then it would add further weight to the suggestion that ‘molar’ factors control this aspect of free-operant performance. In contrast, if this did not impact bout-initiation responding, then it may be that another construct, such as Pavlovian contextual conditioning may play a role in controlling bout-initiation responding.

Method

Participants and Apparatus

Twenty-four participants (10 male and 14 female), between 18 and 23 (mean 19.75 ± 1.95) years old were recruited as described in Experiment 1. Four participants were excluded from the study due to high depression (BDI) scores, leaving 20 participants in the study. The apparatus was as described in Experiment 1.

Procedure

The participants were tested individually as described in Experiment 1. After completing the psychometric tests, they were presented with the instructions as in Experiment 1. Following the instructions, the participants were exposed to three schedule conditions for 3 min each. Each schedule was signaled by a different colored circle on the screen. Participants pressed to space bar to make a response, which subtracted 1 point from their total, and they received 40 points for reinforcement. There was a 30s inter-component interval. The participants initially responded on an RR-30 schedule, where each response had a 1/30 probability of delivering reinforcement. They then responded on an RI+ schedule that programmed reinforcement according to the function: (i / n) * b; where i = the preceding inter-reinforcer interval; n = the number of responses made during the period i; and, b = the equivalent RR value (i.e. 30). A numeric example may serve to illustrate how this schedule works. Assume that the RI+ schedule was to have the molar characteristics of a RR-30 schedule, the time from the last reinforcer was 60s, and that 60 responses had been made during that time. In this case, the interval to reinforcement would equal (60/60)*30 = 30s. During this 30s, at 60 responses per minute, 30 responses would be emitted before the interval would time out. If 30 responses had been made during that 60 s period, then the interval would be: (60/30)*30 = 60s. During this 60s, if responses were being emitted at 30 responses per minute, then 30 responses would be emitted prior to the reinforcer. Alternatively, if 120 responses had been made during the 60s period, the interval became: (60/120)*30 = 15s. During this 15s, at 120 responses per minute, then 30 responses would be emitted prior to the reinforcer. Thus, the interval varies inversely with the rate of responding, and each reinforcer is delivered for about 30 responses. This made the feedback function identical to the RR-30 schedule (see McDowell & Wixted, 1986). The final component was an RI schedule yoked to the RI+ schedule in terms of reinforcement rate. The times between successive reinforcements on the RI+ schedule were noted, and these became the required intervals for successive reinforcers for the RI schedule. Participants experienced 4 blocks of this sequence of schedules.

Results and Discussion

Figure 5 about here

The top panel of Figure 5 shows the mean rate of responding for the schedule conditions in the last block of training, as reliable schedule differences have been shown to emerge prior to this trial number in previous studies (Bradshaw & Reed, 2012). Responding was higher in the RR and RI+ schedules relative to the RI schedule. A repeated-measures ANOVA conducted on these data revealed a significant effect of condition, $F(2,38) = 15.97$, $p < .001$, $\eta^2_p = .457$ [.196 - .603], *Bayes Factor* = .045, $p(H_1/D) = .957$. Pairwise t-tests (with Bonferonni correction: .05/3 = .016) revealed that the RR and RI schedules, $t(19) = 4.95$, $p < .001$, and the

RI+ and RI schedules, *t*(19) = 3.97, $p < .001$, differed from one another, but the RR and RI+ schedules did not differ from one another, $t < 1$. These data replicate previous findings regarding the impact of these schedules on human responding (McDowell & Wixted, 1986; Reed, 2007), and suggest that humans are sensitive to the molar feedback function relating response rate to reinforcement rate.

The bottom panel of Figure 5 shows the log survivor plots for the three schedules, calculated as described in Experiment 1. These data show that the RR and RI+ schedules had highly similar patterns of responding to one another, both showing a rapidly descending initial portion of the plot, indicating high rates of responding in the response-bouts. The RI schedule displayed a different pattern to the other two schedules – having a shallower initial portion of the plot suggesting a lower rate of within-bout responding. However, all three schedules displayed similar gradients to one another in the second portion of the plot, suggesting that initiation rates in all three schedules were similar to one another. The individual subject log survivor plots are shown in Figure 6. The general pattern outlined above – a rapidly descending initial portion in the RR and RI+ schedules compared to the RI schedule is broadly apparent in these data. Although visual inspection reveals a degree of variation between the subjects, there are no apparent sub-groups of participants.

Figures 6 and 7 about here

The top panel of Figure 7 displays the mean bout-initiation rates (solid bars) over the last exposure to each schedule as determined by fitting the equation described in Experiment 1 (Shull, 2014) to the data. Inspection of these data shows that bout-initiation rates were similar on all three schedules, which was confirmed by a repeated-measures ANOVA, $F(2,38) = 1.81$, $p > .10$, $\eta^2_p = .087$ [.000 - .251], *Bayes Factor* = 10.990, $p(H_o/D) = .917$. The bottom panel of Figure 7 shows the within-burst response rates (diagonal bars) were higher in the RR and RI+ schedules than in the RI schedule, which was confirmed by a repeated-measures ANOVA, $F(2,38) = 3.41$, $p < .05$, $\eta^2_p = .152$ [.000 - .330], *Bayes Factor* = .008, $p(H_1/D) = .999$. Pairwise t-tests (with Bonferonni correction: .05/3 = .017) revealed that only the RR and RI schedules differed, $t(19) = 2.74$, $p < .01$.

Overall, these data suggest that human responding is sensitive to the feedback functions relating response rates to reinforcement rates (see also McDowell & Wixted, 1986). There was no difference in the rates of bout-initiation across the three schedules in the current experiment, which suggests that the feedback function relating rate of reinforcement to rate of response does not impact on bout-initiation responses. Rather, as the schedules all had the same rate of reinforcement, due to the yoking procedure, these data suggest that this factor controls the bout-initiation rate. This may also suggest that the degree to which the context receives strength through levels of reinforcement may be a key factor impacting bout-initiation responding. However, the difference in the schedules was manifest in higher within-bout rates being seen in the RR and RI+ schedules.

Experiment 3

Experiments 1 and 2 indicates that human RI response rates can be sensitive to rates of reinforcement as in nonhumans (see also Bradshaw et al., 1976), and that reinforcement rates impacted most strongly on human bout-initiation responding as in nonhumans (Brackney et al., 2011; Reed, 2007; Shull et al., 2001). This provides further evidence that human schedule performance, under the appropriate conditions, is controlled by many of the same factors that control nonhuman performance (see also Reed, 2001; 2015b). However, investigation of the micro-structure of behavior on schedules of reinforcement has also been used to enable a more fine grain analysis of the impacts of contingencies on responding in nonhumans. In many studies of human schedule performance, a response-cost is added to engender greater schedule-typical performance (see Bradshaw & Reed, 2012; Raia et al., 2000; Reed, 2001; Weiner, 1962). Experiment 3 explored whether the response cost impacted on all types of responding, or whether it influenced bout-initiation or within-bout responding most strongly.

Method

Thirty-four participants (14 males and 20 females), between 18 and 26 (*M* = 19.97 ± 1.77) years old, were recruited as described in Experiment 1. The participants were randomly divided into two groups (a high cost group and a low cost group). Four participants were excluded for high depression or schizotypy scores, leaving 30 participants in total (15 per group). The same apparatus was employed as described in Experiment 1. The procedure was identical to Experiment 1 for the low cost group, and was the same for the high cost group, except that each response subtracted 10 points instead of 1 point from the participant's total.

Results and Discussion

Figure 8 about here

The top panel of Figure 8 presents the group-mean overall responses over the last 5 min of training in each schedule condition for both groups. Inspection of these data shows that the overall response rates varied inversely with the interval, and were lower for the high cost group. A two-factor mixed-model ANOVA (schedule x cost) revealed significant main effects of group, *F* (1,28) = 5.92, $p < .05$, $\eta^2_p = .175$ [.002 - .400], *Bayes Factor* = .308, $p(H_1/D) = .764$, and schedule, $F(2,56) = 8.77$, $p < .001$, $\eta^2_p = .239$ [.057 - .393], *Bayes Factor* = .402, $p(H_1/D) = .665$, but no interaction between the two factors, $F < 1$, $p > .40$, $\eta^2_p = .025$ [.000 - .125], *Bayes Factor* = 20.412, $p(H_o/D) = .953$. The bottom panel of Figure 8 shows the log survivor plots for the low cost (left panel) and high cost (right panel) groups for all three schedule conditions, as determined by the methods outlined in Experiment 1.

Figure 9 about here

The top panel of Figure 9 displays the mean bout-initiation rates (solid bars) over the last 5 min of exposure to each schedule for both groups as determined by fitting the equation outlined in Experiment 1 to the data. Inspection of these data shows that bout-initiation were higher on the RI-30s than on either of the other two schedules for both groups, and that bout-initiation rates were higher in the low compared to the high cost groups. A two-way, mixed-model ANOVA (group x schedule) revealed significant main effects of group, $F(1,28) = 12.47$, $p < .001$, $\eta^2_p = .308$ [.057 - .517], *Bayes Factor* = .002, $p(H_1/D) = .997$, and schedule, $F(2,56) = 3.33$, $p < .05$, $\eta^2_p = .106$ [.000 - .251], *Bayes Factor* = .002, $p(H_1/D) = .998$, but no interaction between the two factors, $F < 1$, $p > .90$, $\eta^2_p = .001$ [.000 - .014], *Bayes Factor* = 20.843, $p(H_o/D) = .953$. Paired t-tests adopting a Bonferroni correction

(.05/3 = .017) revealed a significant difference between the RI-30s and RI-60s conditions, $t(29) = 2.22$, $p < .01$.

Inspection of the within-bout response rates (diagonal bars) shown in the bottom panel of Figure 9 reveals that, although there were some numerical differences between the schedules and groups, there was no main effect of group, $F(1,28) = 3.11$, $p > .10$, $\eta^2_p = .100$ [.000 - .321], *Bayes Factor* = .533, $p(H_o/D) = .652$, or schedule, $F < 1$ (.93), $p > .40$, *partial eta*^{2} = .032 [.000:.139], *Bayes Factor* = 7.268, $p(H_o/D) = .879$, or interaction, $F < 1$, $p > .90$, $\eta^2_p = .100$ [.000 - .014], *Bayes Factor* = 15.101, $p(H_o/D) = .938$.

In summary, these results replicated the effect of increasing the RI schedule interval seen in Experiment 1 (see also Bradshaw et al., 1976; deVilliers, 1977), and confirmed that the response cost manipulation was effective in reducing overall levels of responding (Weiner, 1962), which is consistent with nonhuman studies (Reed, 2001). The current experiment also noted that the cost manipulation appeared to differentially impact the bout-initiation responding in comparison with the within-bout rates of responding. Although the manipulation numerically reduced the expression of both forms of responding, it tended to suppress bout-initiation responses to a larger extent than it acted on within-bout responses. Such an impact of response cost on responding, which is more sensitive to molar aspects of the contingency, has not been noted in nonhumans before. However, it is consistent with previous investigations of human causal judgment, where explicit judgments about the relationship between responding and outcomes become more schedule sensitive when greater response costs are imposed (Reed, 2001).

Experiment 4

Experiment 3 noted that the effect of a response cost on human RI responding was to reduce response rate, mainly by acting on bout-initiation rates. Although there is good evidence that the effect of response cost, and the application of a punisher are equivalent in humans (cf. Bradshaw, Szabadi, & Bevan, 1977; Weiner, 1962), it may be that, in the procedure used in Experiment 3, the results were a consequence of the particular combination of reinforcer points value and response cost. In order to explore further the effect of punishment, when operationalized as the application of a stimulus rather than a response cost, Experiment 4 replicated the essential features of Experiment 3 but uses a punisher as employed by Bradshaw et al. (1977). In this latter study, human subjects responded on a VI schedule for money, but on some sessions they also received a reduction in their total money, delivered on a variable ratio (VR) schedule. The current study adopted this design, but using the current procedure to extend and replicate the results of Experiment 3.

Experiments in this report have employed relatively brief exposures to the contingencies. Although this level of exposure has been shown to adequately produce differences in behavior as a result of the schedules, it does differ somewhat from the nonhuman studies, which tend to expose subjects to contingencies for long periods in order to generate what is taken to be stable performance. Experiment 4 sought to explore if longer exposure to the current contingencies would produce any difference in the results. If it did not, then greater confidence could be placed in the results of the preceding studies as reflecting stable impacts on human responding.

Method

Twenty-four participants (8 males and 16 females), between 18 and 28 (M = 21.27 ± 3.06) years old, were recruited as described in Experiment 1. The participants were randomly divided into two groups (a punisher group and a no punisher group). Three participants were excluded for high depression or schizotypy scores, and 6 participants terminated the experiment early, leaving 15 participants in total (n = 8 no punisher; n = 7 punisher). The same apparatus was employed as described in Experiment 1. The procedure was identical to Experiment 1 with the following exceptions. The experiment lasted for a total of 60 min. The group responding without an added punisher received the contingencies described for the RR-30s condition in Experiment 1. For the punisher group, a RR-20 schedule ran concurrently with the RI-30s schedule, and every time that the RR schedule was satisfied, 40 points were subtracted from the points total.

Results and Discussion

Figure 10 about here

The top panel of Figure10 presents the group-mean overall response rate over the early (6-10 min) period of training, and over the late (56-60 min) period of training. The overall response rates were lower for the punished group, and there was no strong effect of training, except that the difference apparent between the groups early in training became slightly larger with extended training. A two-factor mixed-model ANOVA (group x training period) revealed a significant main effect of group, $F(1,13) = 4.31$, $p < .05$, $\eta^2_p = .249$ [.000 - .535], *Bayes Factor* = .453, $p(H_1/D) = .688$, but not of training, $F < 1$, $p > .9$, $\eta^2_p = .005$ [.000 - .149], *Bayes Factor* = 3.859, $p(H_o/D) = .794$, nor was there an interaction, $F < 1$, $p > .60$, $\eta^2_p = .020$ [.000 - .296], *Bayes Factor* = 3.324, $p(H_o/D) = .769$. The bottom panel of Figure 10 shows the log survivor plots for the two groups, early and late in training, as determine by the methods outlined in Experiment 1. These patterns are similar to those from Experiment 3 with regard to the effect of punisher, and did not change greatly between early and late training, except that the patterns in the two groups diverged slightly with extra training.

Figure 11 about here

The top panel of Figure 11 displays the mean bout-initiation rates (solid bars) during early exposure (6-10 min) and late exposure (56-60 min) for both groups as determined by fitting the equation outlined in Experiment 1 to the data. Inspection of these data shows that bout-initiation rate was lower for the punished group (RI-30sP), and that this pattern was apparent both early and late in training. A two-way, mixed-model ANOVA (group x training period) revealed a significant main effect of group, $F(1,13) = 11.22$, $p < .01$, $\eta^2_p = .463$ [.059 - .678], *Bayes Factor* = .036, $p(H_1/D) = .965$, but there was no main effect of training, $F(1,13\ .088) < 1$, $p > .70$, $\eta^2_p = .007$ [.000 - .187], *Bayes Factor* = 3.705, $p(H_o/D) = .787$, or interaction, $F(1,13) = 1.36$, p > .20, $\eta^2_p = .095$ [.000 - .399], *Bayes Factor* = 1.850, $p(H_o/D) = .649$.

Inspection of the within-bout response rates (diagonal bars) shown in the bottom panel of Figure 11 reveals some numerical, but no consistent, differences between the groups across the training periods; there was no main effect of group, $F(1,13) = 3.93$, $p > .06$, $\eta^2_p = .232$ [.000 - .522], *Bayes Factor* = .533, $p(H_o/D) = .347$, or schedule, $F < 1$, $p > .70$, $\eta^2_p = .008$ [.000 - .240], *Bayes Factor* = 3.644, $p(H_o/D) =$ .785, or interaction, $F < 1$, $p > .60$, $\eta^2_p = .049$ [.000 - .330], *Bayes Factor* = 2.651, $p(H_o/D) = .726$.

These results replicated the effect of adding greater punisher to an RI schedule noted in Experiment 3. This finding also corroborates the cross-experimental comparison of the results presented by Weiner (1962) and Bradshaw et al. (1977) regarding the similar impacts of response cost and punishment presented on a VR schedule, respectively, that both forms of punishment act similarly on human schedule responding. The current punisher manipulation impacted the bout-initiation responding more than the within-bout rates of responding. The data also suggest that the impacts of these manipulations noted in Experiments 1 to 3 in the current report may not be greatly affected by extended exposure to the contingencies, and confirm the assumption that human responding in such procedures stabilizes relatively quickly (see Bradshaw & Reed, 2012). In fact, it proved difficult to convince all participants to continue with the study, as they found pressing buttons on such a task some tedious.

General Discussion

The current studies explored the micro-structure of human responding on free-operant schedules. Experiments 1, 2, and 3 found that overall response rates were directly related to the rate of reinforcement; with shorter interval values producing higher rates of response (see also Bradshaw et al., 1976). Experiment 2 noted that overall rates of responding on an RI schedule were lower than those on an RR schedule matched for rate of reinforcement (see Peele et al., 1984; Reed, 2007; Zuriff, 1970, for similar results with nonhumans). Experiment 2 also replicated the finding that humans respond faster on an RI+ schedule than a RI schedule matched for rates of reinforcement (McDowell & Wixted, 1986; Reed, 2007). These findings indicate that the current procedures were effective in establishing control over human free-operant responding (see also Bradshaw & Reed, 2012; Raia et al., 2000). The performance of the human participants in the current experiments was also found to be divided into two distinct classes of responses: bout-initiation and within-bout responding. This finding has also been described for nonhumans in many studies (Brackney et al., 2011; Killeen et al., 2002; Pear & Rector, 1979; Reed, 2007; Shull et al., 2001), but has not often been investigated for humans (see Reed, 2015b).

The finding of two distinct response classes was noted in all current experiments, and these types of response class were found to be controlled by different aspects of the schedule contingency (see Bowers et al., 2008; Pear & Rector, 1979; Reed, 2011; Shull et al., 2011; Shull & Grimes, 2003). Irrespective of the overall rates of response, human rates of bout initiation were greater with lower interval values than with higher interval values (see Brackney et al., 2011; Bower et al., 2008; Killeen et al., 2002; Reed, 2011; Shull, 2011; Shull et al., 2001). This finding occurred irrespective of the schedule of reinforcement employed (cf. Experiment 1 and 3), and is also consistent with the view that bout-initiation responses are sensitive to overall rates of reinforcement (Killeen et al., 2002; Shull, 2011). In contrast, human within-bout responses on RI schedules appear not to be sensitive to the reinforcement rate, but tend to mirror the overall rates of responding noted (see Reed, 2011; Shull et al., 2001, for a similar finding with nonhumans). A further consistent finding in the current series of studies was that the number of responses per bout was not related to the reinforcement frequency (see Reed, 2011;

Shull & Grimes, 2003, for similar findings in nonhumans). These findings imply that human free-operant responding is composed and controlled in a similar fashion to those rates in nonhumans (see also Reed, 2015b), at least when measures were taken to bring human responding under schedule control (see Raia et al., 2000).

The current studies also explored novel factors that might exert influence on the two types of responding, and focused on two additional aspects of schedule contingencies – the response-reinforcer feedback function (McDowell & Wixted, 1986; Reed, 2007), and response-cost or punishment (Bradshaw and Reed, 2012; Raia et al., 2000). It was noted that the response cost/punishment manipulation tended to impact most strongly on the bout-initiation responses compared to the within-bout responding (Experiments 3 and 4). The sensitivity to the response-reinforcer feedback function was noted in Experiment 2 (see also McDowell & Wixted, 1986; Reed, 2007), but was not reflected in an impact on the bout-initiation responses, but on the within-bout responding.

Thus, pattern of results emerge in which reinforcement rate and response cost (as defined by removing reinforcement points) impact bout-initiation responding, and the response-reinforcer feedback function impacts within-bout responses, like reinforcement of IRTs (see Shull, 2011). This finding with respect to the feedback function appears contrary to received wisdom regarding the factors impacting the bout-initiation and within-bout responding. Previously, molar factors have been suggested to impacted the former type of responding (Reed, 2011; 2015; see Shull, 2011, for a review), and, in this sense, the response-reinforcer feedback function is taken to be molar (McDowell & Wixted, 1986). However, the current data provide a different suggestion – namely, factors which impact the strength of Pavlovian conditioning of the context might affect bout-initiation responses. Both the rate of reinforcement and punishment would impact context conditioning. In contrast, neither IRT reinforcement (see Reed, 2011; 2015a; Shull, 2011) nor the response-reinforcer feedback function would impact the Pavlovian strength of the context, as they would neither add nor subtract reinforcement to that context.

Thus, bout-initiation responding might be taken as an index of the motivation state of the participant. This would tie to recent suggestions made by Reed (2015c) regarding the impact of context conditioning on human judgment of causality and their motivation to respond in a particular context. It would also predict that increasing the availability of response non-dependent reinforcement would increase rates of bout-initiation, while overall rates may decrease, as this factor has been suggested to affect contextual conditioning and response strength (Nevin & Grace, 2000), as well as motivation to respond (Reed, 2015c). Although Shull et al. (2001) did explore the impact of response-independent reinforcement on the microstructure of responding, they kept overall rates of reinforcement constant as they varied the proportion of reinforcement obtained from each source, which, according to the above view, would keep the value of the context stable.

There are a few caveats that limit the weight that might be placed on such an interpretation, and which will require further investigation. For example, Brackney et al. (2011) noted noted that changes in the effort required (high lever vs. low lever) affected bout-initiation rate. If bout-initiation rate were selectively sensitive to stimulus-outcome associations, effort requirement should not impact it. However, impacted the rate of responding through introducing a form of response cost will reduce rate of responding (Experiment 3), and impacting the rate of response may well impact rate of reinforcement, which would impact the motivational status of the context.

The current studies also employed only one of the many methods that can distinguish between bout-initiation and within-bout responding, such as the cut-off value (see Shull, 2011). It should be noted that, while the log survivor procedure avoids the arbitrary selection of a cut-off value, it makes assumptions about the fit of the data to such a two-process model (Bowers et al., 2008). A difficulty with this approach is that there are a number of different proposals for modeling the data (Kessel & Lucke, 2008; Killeen et al., 2002; Shull, 2011), and it is not clear which is most appropriate for human responding. The original method suggested by Shull (2001) was adopted for the current data, as this has the best documented association with the factors that influence the ‘bout-initiation’ and ‘within-bout’ responding – the main aim of the current study. Additionally, the double exponential method (Shull, 2001) requires many IRTs to get very precise parameter estimates. The current samples were much smaller than this, and the resulting imprecision of the current analysis (which is likely underestimating within-bout response rate) is acknowledged.

The current data show some similarities between human and nonhuman performance on schedules of reinforcement at both the overall and the structural levels of responding (see also Raia et al., 2000; Reed, 2015b). Such similarities are not novel (e.g., Bradshaw & Reed, 2013; Randell et al., 2009; Raia et al., 2000), but are not always noted (see Lowe, 1979). If human and nonhuman performance on schedules can be shown to be similar, under some circumstances, and this may well allow investigation of many important applied areas, such as behavioral psychopharmacology, to be conducted with the species to which the results are directly relevant. Nevertheless, the conditions under which human subjects were studied in the current series do differ from the studies of nonhumans reported elsewhere, especially in terms of the amount of training given, which is much greater in the previous nonhuman studies.

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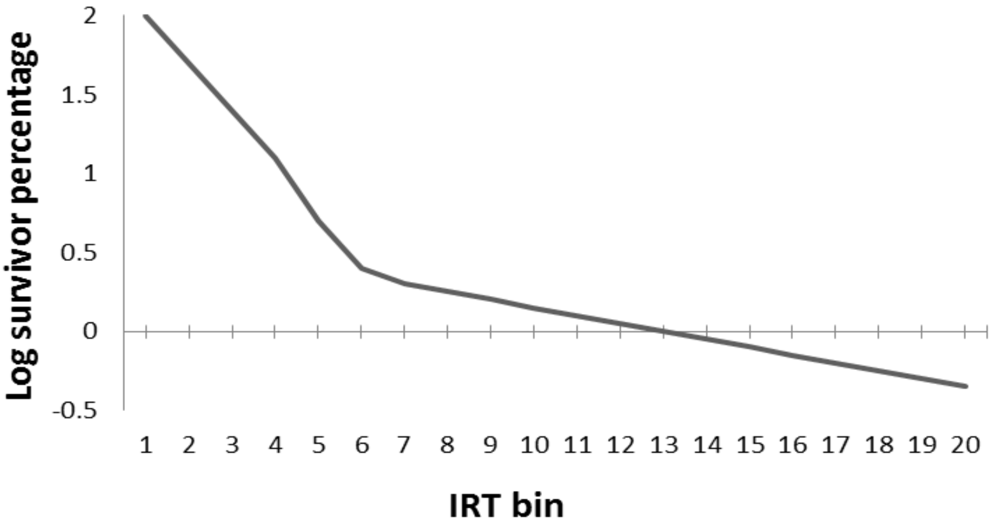

Figure 1. Idealized log survivor plot for successive inter-response time (IRT) bins.

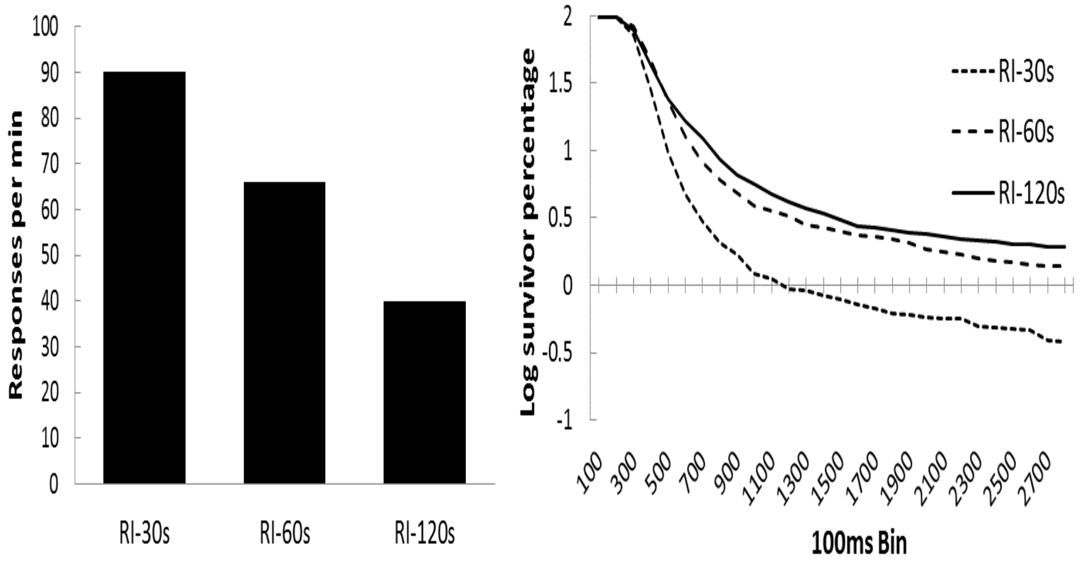

Figure 2. Experiment 1. Left panel = mean response rate for each condition. Right panel = log survival plots for the three schedules. Due to the within-subjects nature of this experiment, no error bars are provided.

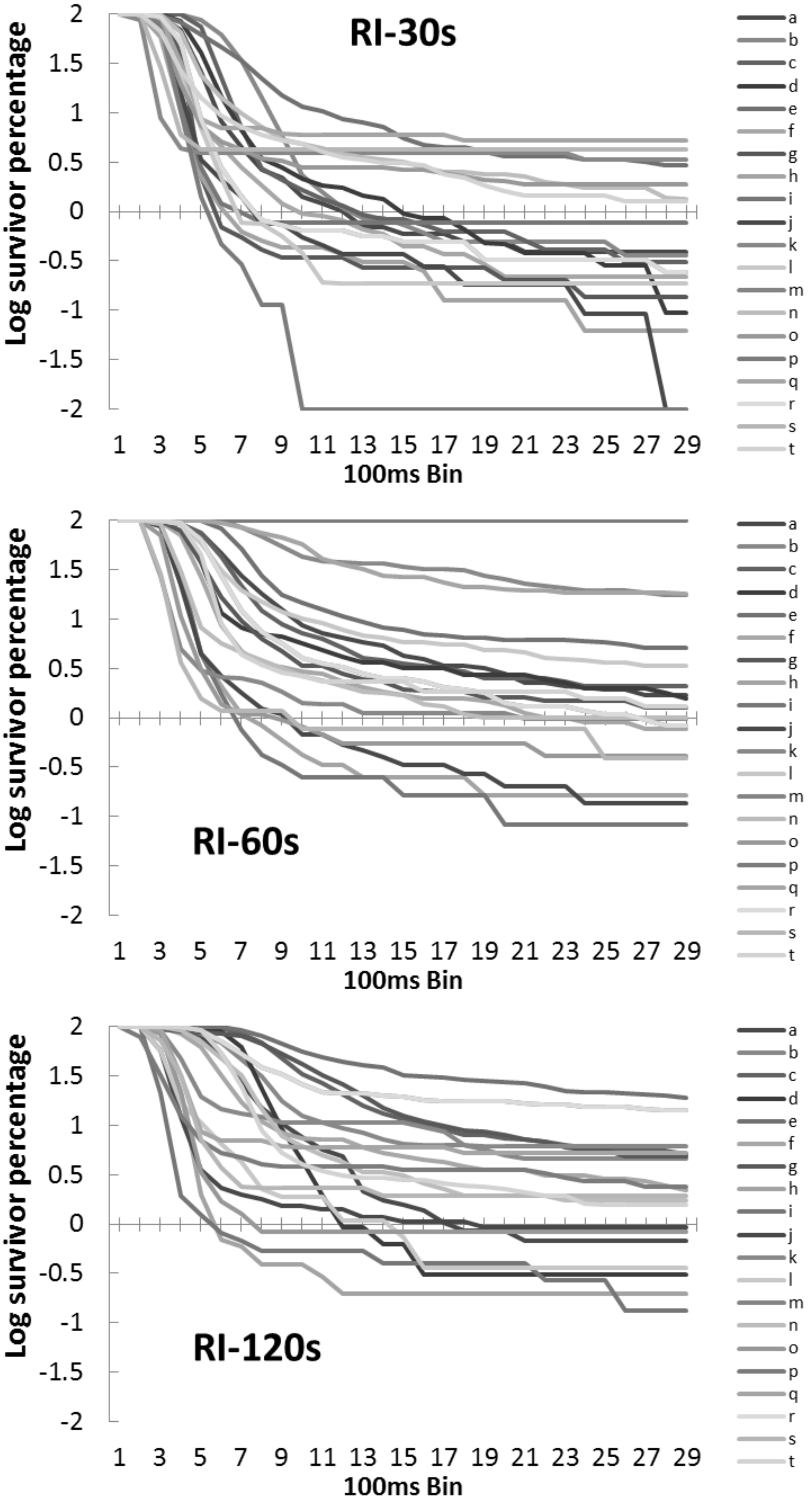

Figure 3. Experiment 1. Log survivor plots for individual subjects for the three schedule conditions.

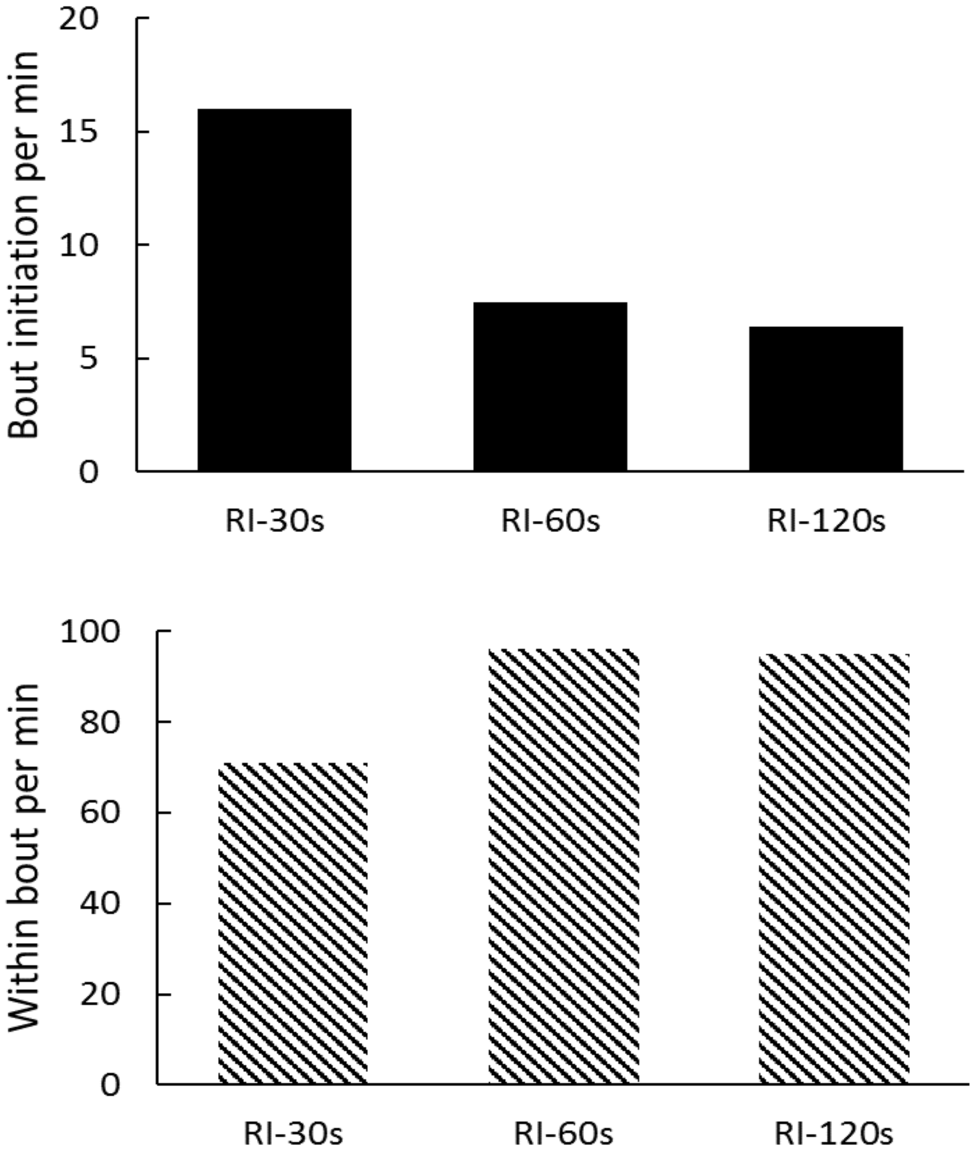

Figure 4. Experiment 1. Log survivor method to calculate mean response rates over the last 5 min of exposure to each schedule. Top panel = mean bout initiation rate. Bottom panel = mean within bout rate. Due to the within-subjects nature of this experiment, no error bars are provided.

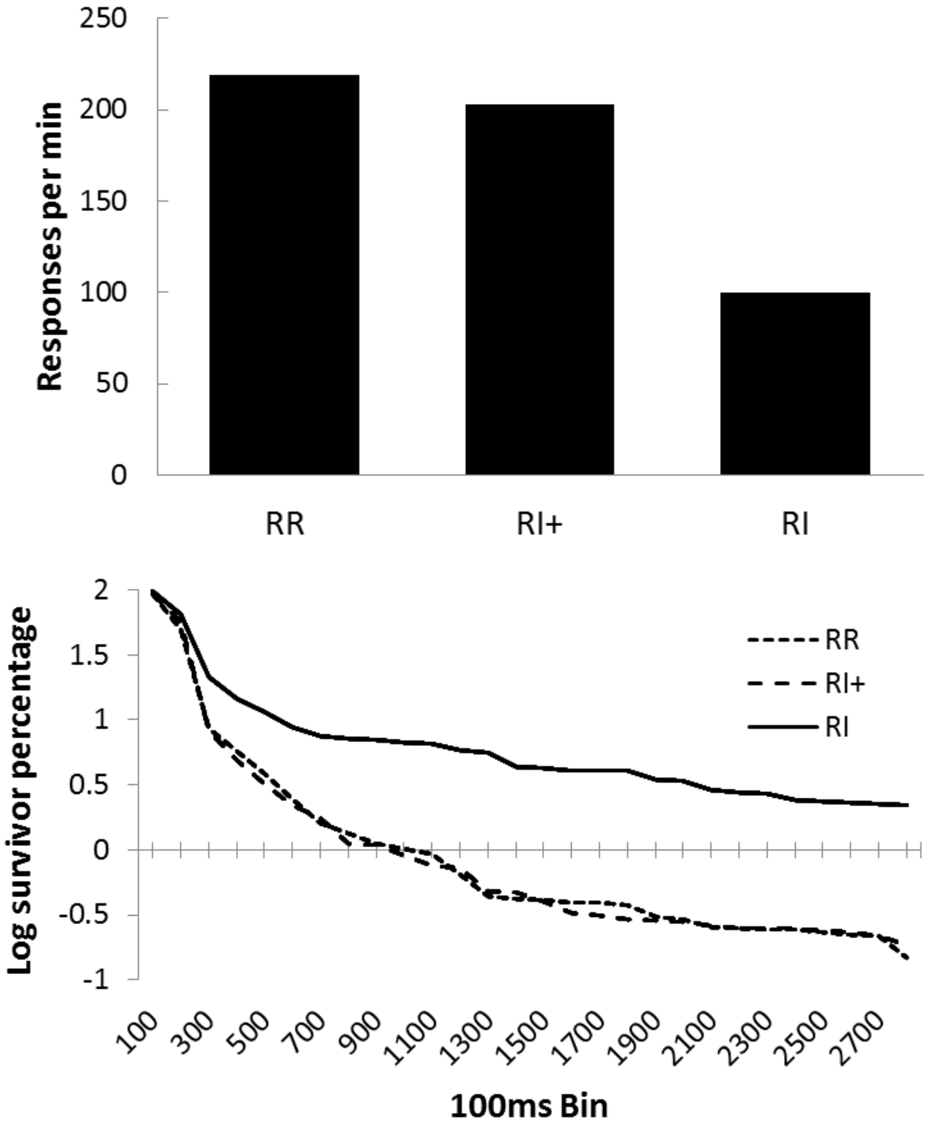

Figure 5. Experiment 2. Top panel = overall responses rates across for each schedule. Bottom panel = log survival plots for the three schedules. Due to the within-subjects nature of this experiment, no error bars are provided.

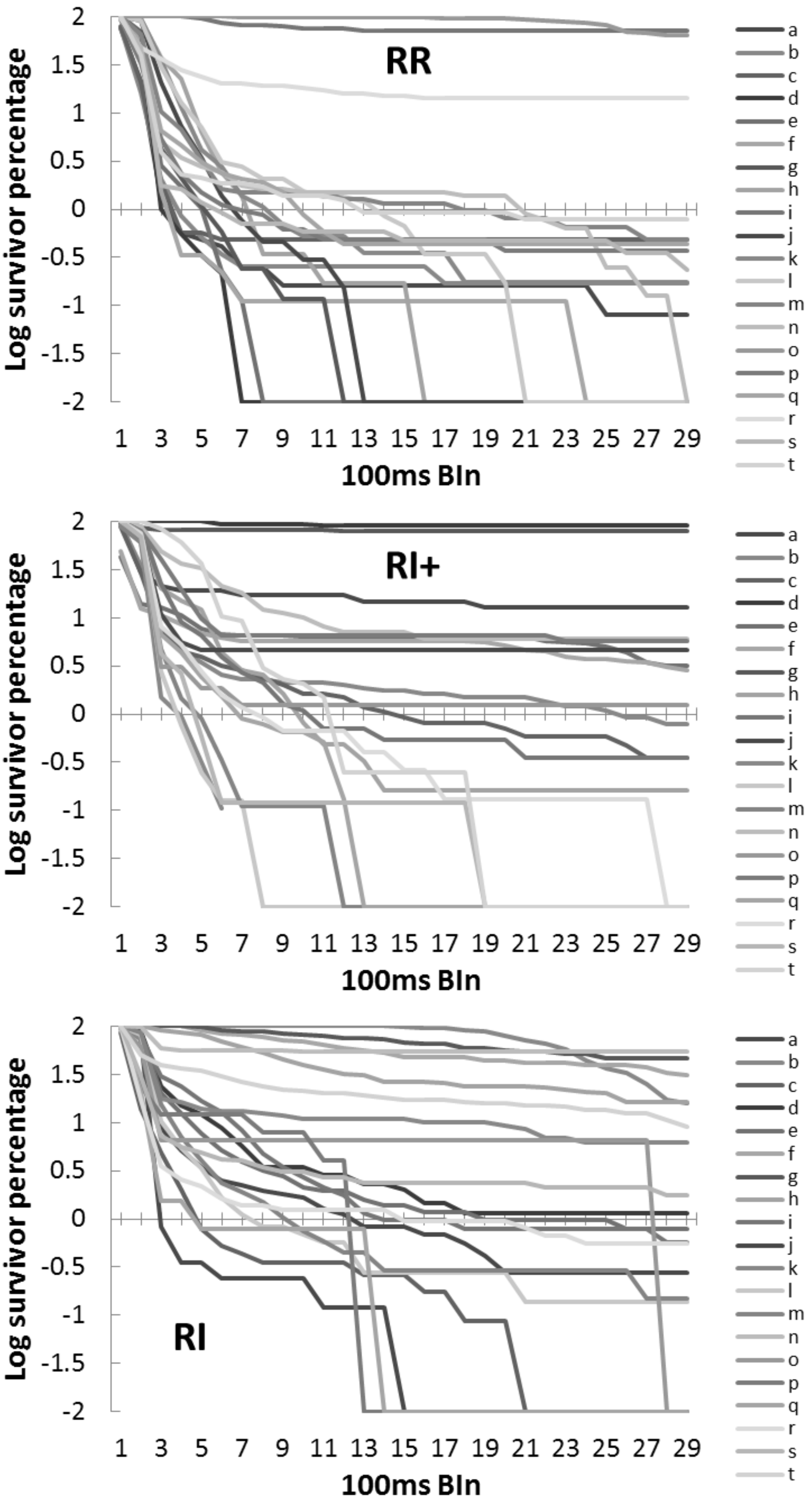

Figure 6. Experiment 2. Log survivor plots for individual subjects for the three schedule conditions.

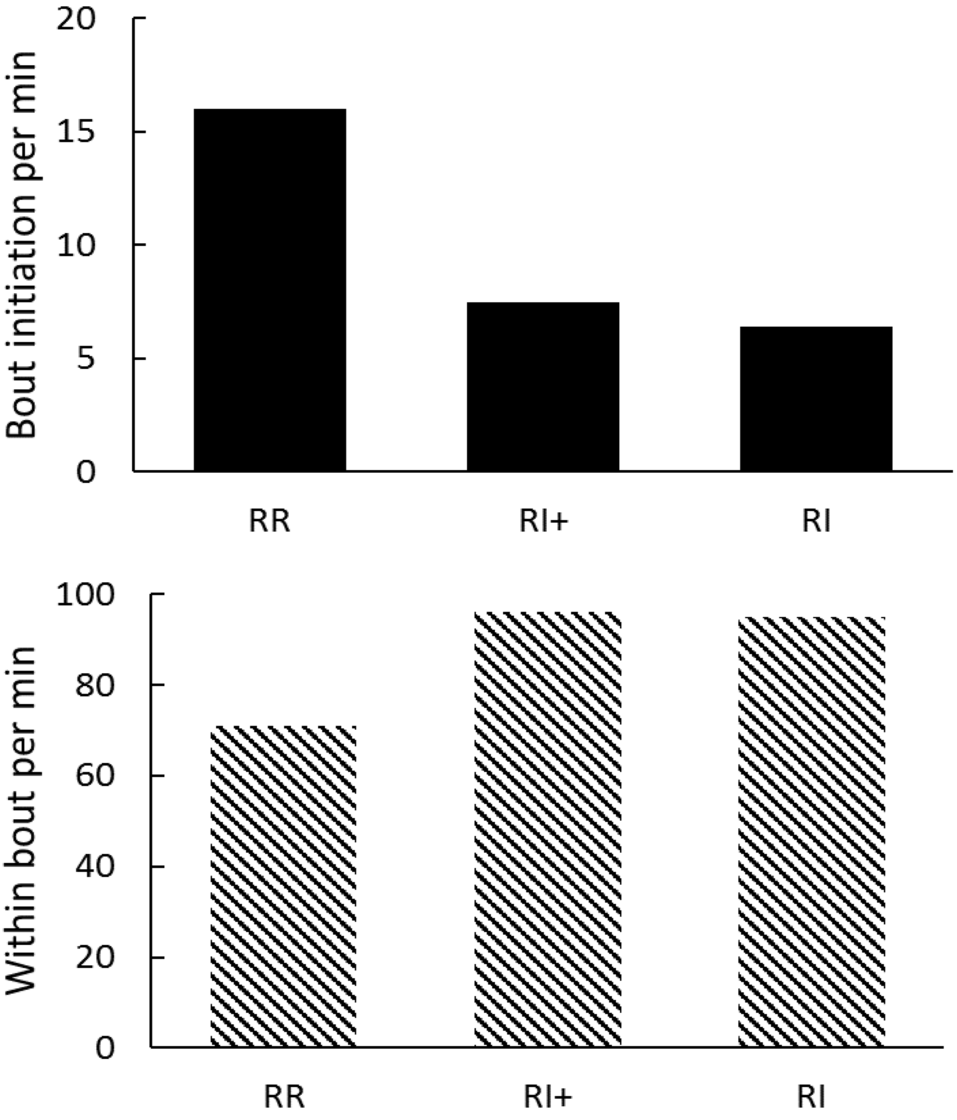

Figure 7. Experiment 2. Log survivor method to calculate response rates over the last block of exposure to each schedule. Top panel = mean bout initiation rate. Bottom panel = mean within bout rate. Due to the within-subjects nature of this experiment, no error bars are provided.

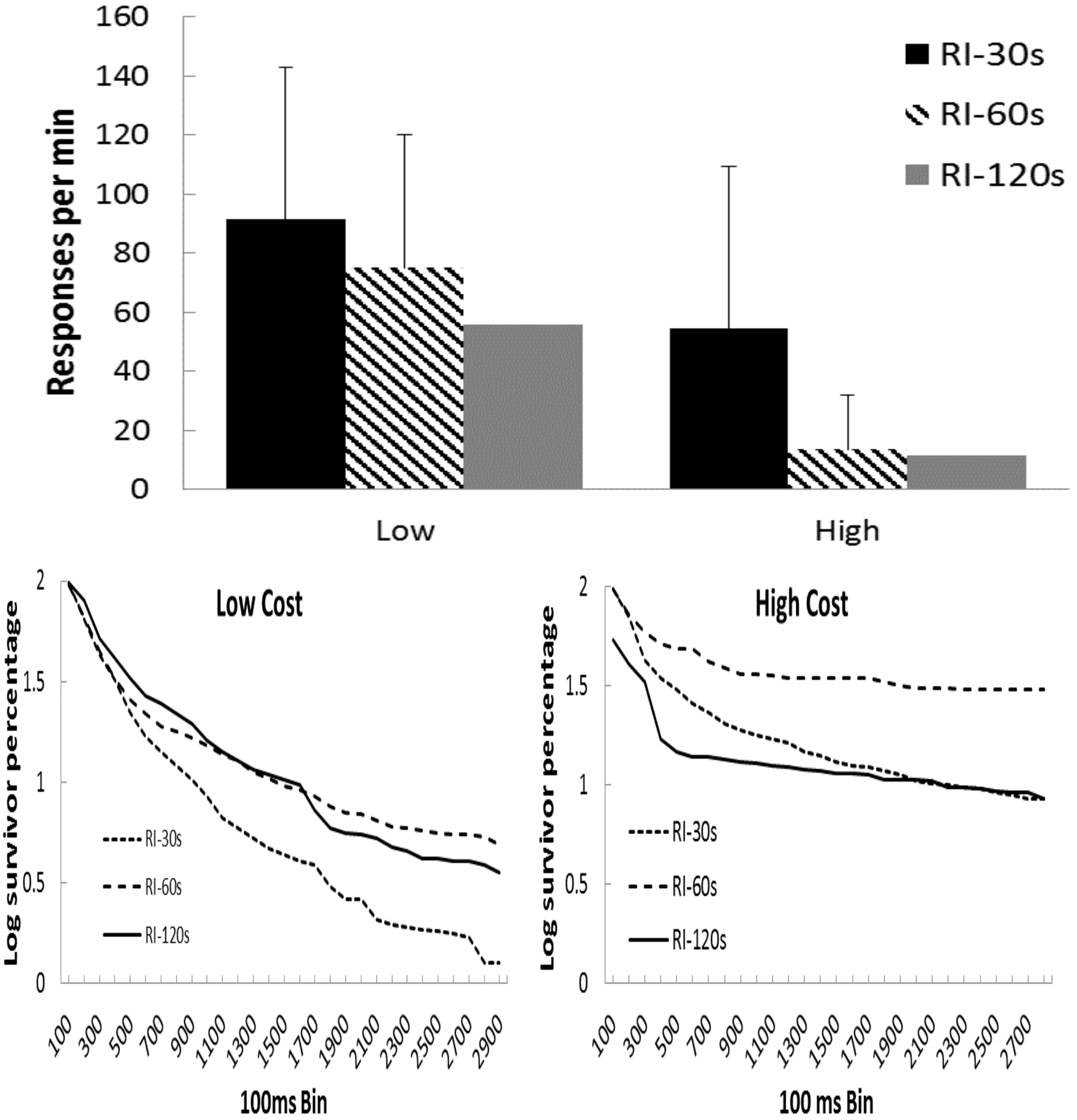

Figure 8. Experiment 3. Top panel = overall responses rates across for each schedule in both groups. Error bars = 95% confidence intervals. Bottom left panel = log survival plots for the three schedules in the low cost group. Bottom right panel = log survival plots for the three schedules in the high cost group. Low – low-cost group; high = high-cost group.

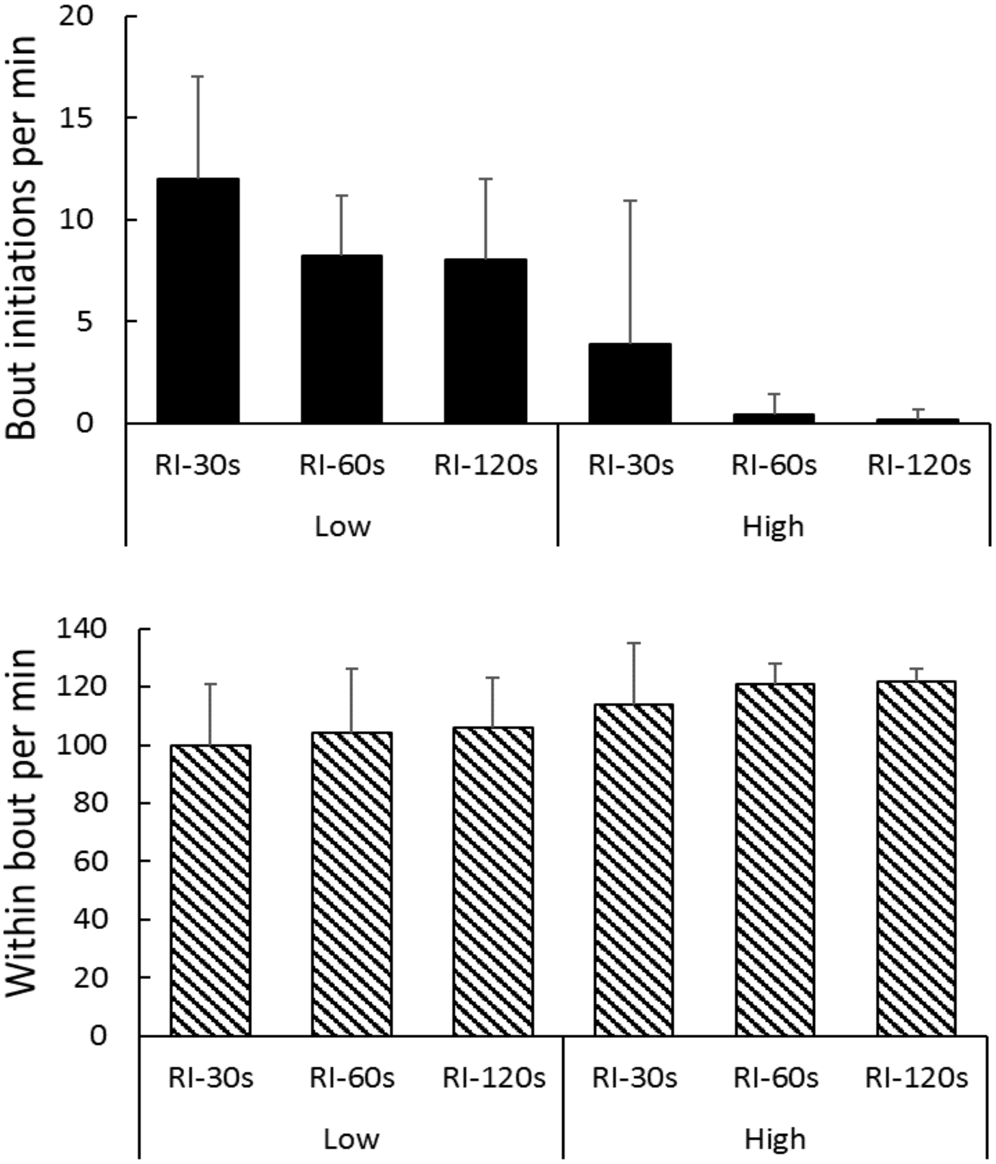

Figure 9. Experiment 3. Log survivor method to calculate response rates over the last 5 min of exposure to each schedule. Top panel = mean bout initiation rate. Bottom panel = mean within bout rates. Error bars = 95% confidence intervals.

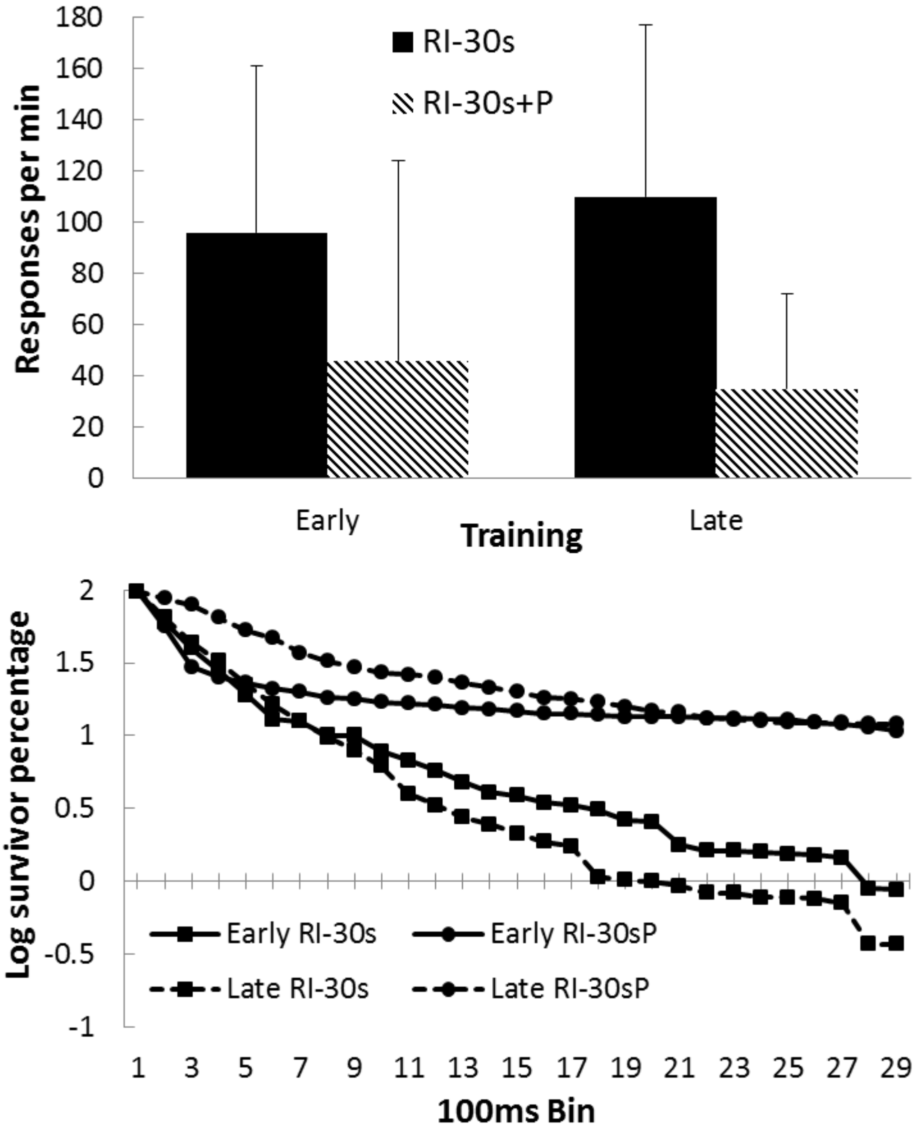

Figure 10. Experiment 4. Top panel = overall responses rates for both groups early and late in training. Error bars = 95% confidence intervals. Bottom left panel = log survival plots for the two groups early and late in training. RI-30s = no punisher added; RI-30sP = punisher added on RR-30 schedule.

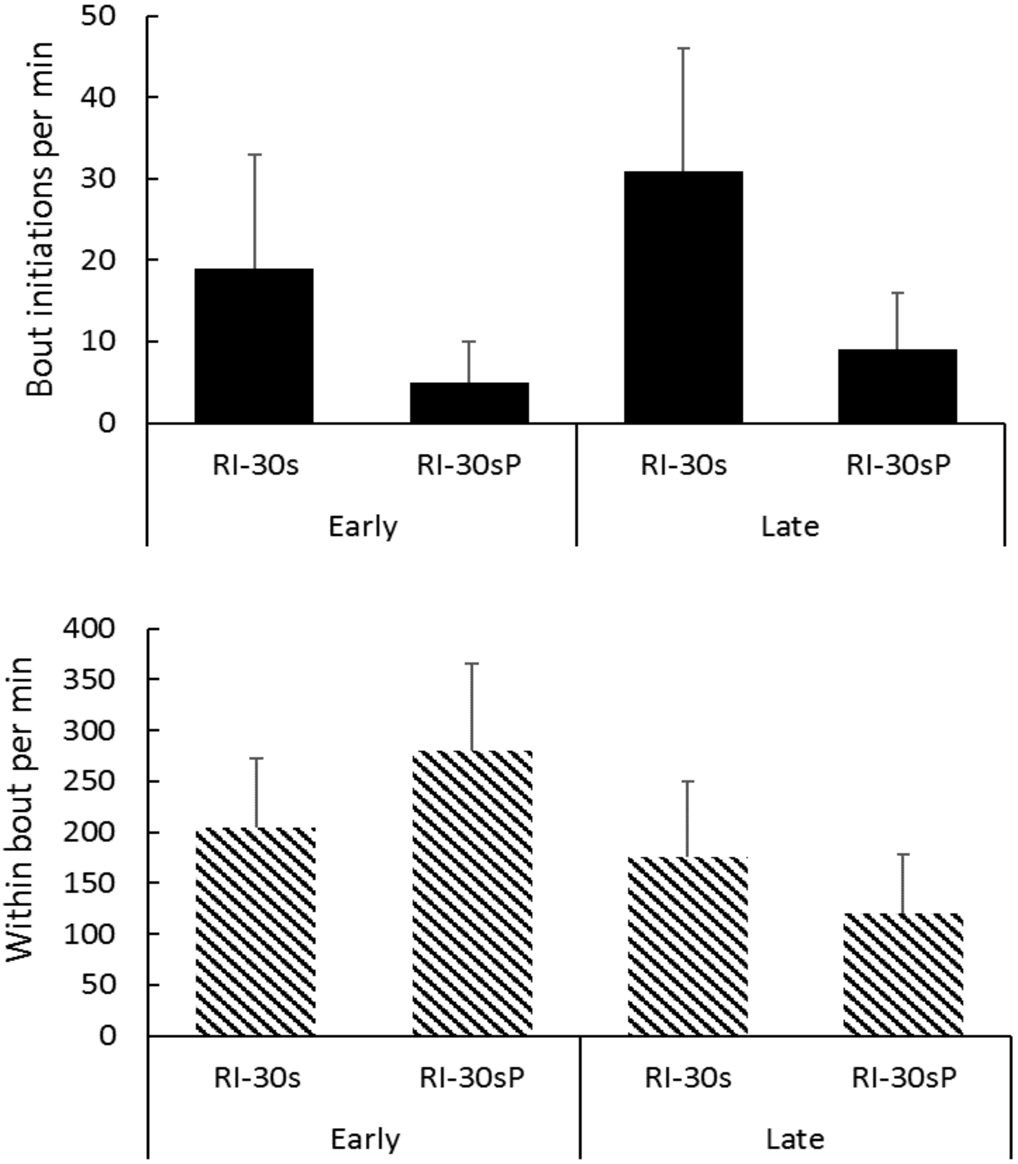

Figure 11. Experiment 4. Log survivor method to calculate response rates over the last 5 min of exposure to each schedule. Top panel = mean bout initiation rate. Bottom panel = mean within bout rates. Error bars = 95% confidence intervals. RI-30s = no punisher added; RI-30sP = punisher added on RR-30 schedule.