Factors controlling the micro-structure of human free-operant behaviour: Bout-initiation and within-bout responses are effected by different aspects of the schedule

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Short title: Human schedule performance.

Abstract

Two experiments examined factors controlling human free-operant performance in relation to predictions based on the nature of bout-initiation and within-bout responding. Overall, responding was higher for a random ratio (RR) than a random interval (RI) schedule, with equal rates of reinforcement. Bout-initiation rates were not different across the two schedules, but within-bout rates were higher on the RR schedule. Response cost reduced overall rates of responding, but tended to suppress bout-initiation responding more than within-bout responding (Experiments 1 & 2). In contrast, reinforcement magnitude increased all forms of responding (Experiment 2). One explanation consistent with these effects is that bout-initiation responses are controlled by overall rates of reinforcement through their impact on the context (i.e. are stimulus-driven), but that within-bout responses are controlled by response reinforcement (i.e. are goal-directed). These current findings are discussed in the light of these theoretical suggestions.

Keywords: schedules of reinforcement; bout-initiation; within-bout responding; response cost; reinforcement magnitude; actions and habits; humans.

Response rates are typically higher on random ratio (RR) than random interval (RI) schedules of reinforcement when the rates of reinforcement on these schedules are equated (Ferster & Skinner, 1957; Peele, Casey, & Silberberg, 1984; Zuriff, 1970). This finding has formed the basis of numerous investigations of the factors that control free-operant responding, and has underpinned several theoretical accounts of schedule-maintained behaviour (Peele et al., 1984; Reed, 2015; Zuriff, 1970). Recent analysis of schedule-controlled responding has suggested that two forms of responding are present: 'bout-initiation' responding and 'within-bout' responding' (Killeen, Hall, Reilly, & Kettle, 2002; Shull, 2011; Shull, Gaynor, & Grimes, 2001). 'Bout-initiation' responding refers to the first responses in any particular bout of behavioural engagement (e.g., the first response from a set of responses made to a lever); whereas, 'within-bout' responding comprises all of the responses that follow in that particular engagement.

These aspects of responding are controlled by different aspects of contingencies. 'Bout-initiation responding co-varies with overall rates of reinforcement (Killeen et al., 2002; Shull, 2011; Shull et al., 2001), and is hypothesised to be stimulus-driven – that is, dependent on eliciting cues (Reed, 2020), and controlled by factors that influence the degree to which the context gains strength – that is, the degree to which it is associated with the delivery of the reinforcer (Reed, Smale, Owens, & Freegard, 2018). 'Within-bout' responding is influenced by the shaping effects of reinforcement on responding (Reed et al., 2018; Shull, 2011), such as the reinforcement of particular inter-response times (Peele et al., 1984), and is hypothesised to be goal-directed (Reed, 2020).

Previous explorations have shown that human schedule performance also comprises these forms of responding, which are controlled by some of the same factors that control such responding in nonhuman subjects (Reed, 2015; Reed et al., 2018). In addition, it has been suggested that human 'bout-initiation' responding is 'habitual' and 'automatic' in nature, and

not under conscious control; whereas, 'within-bout' responding is goal-directed and under conscious control (Chen & Reed, 2020; Reed, 2020). For example, Chen and Reed (2020) found that instructions, known to impact human responding (Hayes, Brownstein, Zettle, Rosenfarb, & Korn, 1986), and act on consciously controlled but not habitual automatic responses (Aarts & Dijksterhuis, 2000), affected 'within-bout', but not 'bout-initiation', responding.

The current series of studies develops the exploration of the nature of the micro-structure of human schedule responding (e.g., on 'bout-initiation' and 'within-bout' responding) by examining how factors known to be important for free-operant responding impact bout-initiation and within-bout responding. Response cost (Kazdin, 1972), and reinforcer magnitude (Bonem & Crossman, 1988), have both been suggested as important in the control of schedule performance, but have not been explored deeply in the context of human free-operant behaviour or its micro-structure. This examination will be conducted in the light of theoretical predictions regarding the likely source of impact of such factors – i.e. on stimulus-driven or goal-directed behaviours, and their hypothesised impact on 'bout-initiation' and 'within bout' responding (Reed, 2020). Such an examination should not only elucidate the nature of the control over these schedule micro-behaviours, but also extend theoretical understanding of these response types.

Response cost is an important factor in the maintenance of schedule-controlled behaviour (Azrin & Holz, 1966; McMillan, 1967; Pietras, Brandt, & Searcy, 2010; Weiner, 1964), and its effects are easy to quantify (Bennett & Cherek, 1990; Bradshaw, Szabadi, & Bevan, 1978; Pietras et al., 2010). It refers to factors associated with making a response, such as required force of the response, or whether making the response involves reducing the obtained value of a reinforcer. Research with nonhuman subjects has found that response cost decreases rates of responding, irrespective of its effect on reinforcement rate (Pietras &

Hackenberg, 2005; Raiff, Bullock, & Hackenberg, 2008). Such a response cost manipulation on an RI schedule suppressed human bout-initiation responding more than within-bout responding, although the impact on an RR schedule was unclear (Reed et al., 2018). This differential suppressive effect on the microstructure of schedule responding was taken to reflect that response may impact the Pavlovian value of the context by adding a negative outcome into the context, separable from the value of reinforcer (Raiff et al., 2008), and, thus, impact stimulus-driven bout-initiation responses (Reed et al., 2018).

Reinforcer magnitude has been suggested to impact patterns of human schedule responding. Larger reinforcer magnitudes tend to lead to higher response rates (Bonem & Crossman, 1988; Gentry & Eskew, 1984; Hendry, 1962). Buskist, Oliveira-Castro, and Bennett (1988) examined the effect of response-correlated increases in the reinforcer magnitude on human behaviour, and noted that a positive correlation between reinforcer magnitude and response rates led to higher response rates than a fixed-correlation procedure. However, the impact of reinforcement magnitude on responding is not always noted (Dougherty & Cherek, 1994; Reed, 1991). In terms of the predicted effect of reinforcement magnitude on the micro-structure of schedule-controlled performance, reinforcer magnitude has been suggested to have dual impacts on responding (Killeen, 1985). Firstly, it is suggested to energise general levels of activity (Killeen, 1985), perhaps through conditioning goal-related cues (Pereboom & Crawford, 1958), which should impact bout-initiation responding (Reed et al., 2018; Reed, 2020). Secondly, it has been taken to act directly on goal-directed behaviour by strengthening to tendency to emit the preceding responses (Reed, 1991). Given such theoretical speculation, in contrast to response cost (which is taken to act more on bout-initiation than within-but responses), reinforcement magnitude should act on both types of responses.

A number of different procedures have been adopted to explore the micro-structure of free-operant responding (Killeen et al., 2002; Mellgren & Elsmore, 1991; Reed, 2011; Shull, 2011; Sibley, Nott, & Fletcher, 1990). As these approaches tend to produce the same pattern of results (Chen & Reed, 2020; Reed et al., 2018), the more commonly adopted 'log survivor method' was used for the current set of studies. This method calculates the number of inter-response times (IRTs) emitted in particular time-bins, and turns these into a percentage of all responses not yet emitted. This percentage is then turned into a log. The slope of a resulting log survivor plot is an indicator of the response rate: the steeper the slope, the higher the rate of responding. The slope of log survival plots is not uniform, but comprises an initially steep slope (bout-initiation responses), followed by a shallow slope (within-bout responses), indicating the presence of two different types of responding. A double exponential equation can be fitted, where the equation fits the two distributions of IRTs (i.e. those prior to the 'break', taken to represent response initiations; and those after the break, taken to represent within-bout responses). This equation takes the form: Ppred = a*exp(-bt)+(1-a)*e(-dt); where b and d represent the rates of within-bout and bout-initiation, respectively.

The present study aimed to examine the relationship between micro-responding observed on RR and yoked RI schedules, and both response cost and reinforcer magnitude. This investigation was aimed at further understanding the factors controlling human schedule behaviour, and at elucidating the mechanisms that might underpin this behaviour.

Experiment 1

Previous studies have demonstrated that overall responding is higher on RR than RI schedules with equal rates of reinforcement (Peele et al., 1984; Reed et al., 2018). When the micro-structure of responding is analysed, within-bout, but not bout-initiation, responding

follows this same pattern (Chen & Reed, 2020; Reed et al., 2018). Response cost manipulations reduce the overall rates of responding for nonhuman subjects (McMillan, 1967; Pietras et al., 2010) and human participants (Reed, 2001; Weiner, 1962). Such a manipulation on an RI schedule suppressed bout-initiation responding more than within-bout responding (Reed et al., 2018). This differential suppressive effect was taken to reflect that response cost would tend to impact the Pavlovian value of the context, and, thus, impact stimulus-driven, bout-initiation responses (Reed et al., 2018). One aim of Experiment I was to replicate and extend the previous explorations of the effects of response cost on human schedule behaviour.

The effects of response cost on RR schedules have not been investigated extensively. One theoretical possibility is that such a manipulation may not greatly impact responding on RR schedules, as this schedule tends to produce more goal-directed responding, due to the stronger relationship between responding and reinforcement (Pérez, Aitken, Zhukovsky, Soto, Urcelay, & Dickinson, 2016). If response costs tend to have their impact through effecting the value of the context driving bout-initiation responding (Reed, 2020), then the effects of response cost may not be as pronounced on an RR schedule as it is on an RI schedule.

To test these possibilities, participants were randomly split into two experimental groups: a 1-point response cost group, and a 10-point response cost group (following Reed et al., 2018). Additionally, procedures highlighted as important in previous studies were adopted to bring the human schedule performance under greater schedule control; that is by using: a response cost (Raia et al., 2000), a verbal suppression task (Bradshaw & Reed, 2012), and screening for aberrant personality types as individuals high in depression and schizotypy show atypical schedule performance (Dack, McHugh, & Reed, 2009; Randell, Ranjith-Kumar, Gupta, & Reed, 2009).

Method

Participants

A sample of 48 adult participants (36 male, 12 female) was recruited from a Chinese company. The participants were all Chinese, and aged between 18 and 54 years (mean= 37.29 $\pm$ 9.93 SD). Participants received a financial payment (50 RMB per hour). No participant reported any previous history of mental illness. However, 4 participants were excluded on this basis of high depression and schizotypy scores (Dack et al., 2009; Randell et al., 2009), leaving 44 participants in the study.

Materials

Beck's Depression Inventory (BDI; Beck et al., 1961, Chinese version from Wu & Chang, 2008) is a 21-item questionnaire that measures the clinical symptoms of depression through asking about feelings during past few weeks. The score ranges from 0 to 63, with an internal reliability (α) between .73 and .92 for a non-psychiatric population (Beck et al., 1988). The reliability and validity of the scale are supported in Chinese translation (Wu & Chang, 2008). A score of greater than 9 is taken as showing some level of depression (Beck et al., 1961)

Oxford Liverpool Inventory of Feelings and Experiences-Brief Version (O-LIFE (B); Mason, Linney, & Claridge, 2005, translated into Chinese for this study) is designed to assess schizotypy in a healthy population, and contains 43 questions, under four subscales (unusual experiences, UE; cognitive disorganisation, CD, introverted anhedonia, IA, and impulsive nonconformity, IN). The internal reliability (Cronbach α) of the scales is: UE = .80; CD = .77; IA = .62; IN =.63 (Mason et al., 2005, Randell et al., 2009). A score one standard deviation above the mean on the UE scale has been taken as indicating some degree

of deviation from the norm in terms of schedule behaviour, in that response rates on RR schedules are not demonstrably greater than those on matched RI schedules (Randall et al., 2009).

Apparatus

The experimental task was presented on a standard desktop computer. Visual Basic (6.0) was used to programme the task. The computer task was presented on a white screen, with a stimulus box placed in the centre upper portion of the screen. The box was approximately 8cm wide × 3cm high, and was blocked with a single colour (either blue or pink), to indicate the schedule type (each schedule was associated with a particular colour for each participant). Underneath the colour stimulus box, the word "POINTS" (in capital letters) was positioned, and below this, the running total of the points accumulated appeared in figures.

Procedure

Participants were tested individually in a quiet room, which contained a desk and computer, with the monitor situated approximately 60cm from them. Participants gave written consent, and read the study information and instructions for the task. Participants commenced the task in their own time, and were required to fill in basic demographic details about themselves, along with the psychometric questionnaires, before the schedule task was presented.

Each schedule presentation (trial) was 4min long, and a RR schedule trial was always presented immediately prior to the yoked RI schedule trial. The procedure of yoking RI trials to preceding RR trials ensured that reinforcement in the RI schedule was delivered after a

similar elapse of time that it had taken for the corresponding reinforcers to be awarded on the RR trial.

On the RR-30 schedule, points were awarded after each space bar response with a 1/30 probability. On the following RI schedule, points were awarded following the first response after a specified amount of time had elapsed. The RI schedule was yoked to the preceding RR schedule, so that each successive reinforcement in the RI schedule was delivered only after the elapse of time that it had taken for the corresponding reinforcer to be awarded on the RR trial. There were 4 such RR-RI pairs of schedule presentations (i.e. 8 trials in total). A new schedule was indicated by the colour in the box changing. For the first trial (RR) it was blue (for half the participants), followed by pink for the second trial (RI), and alternated, in this manner, for the subsequent trials. Participants were informed that the box would change colour when a new trial commenced but were not informed of which schedule type the colour indicated.

Each reinforcer in each condition consisted of 40 points being added to the participant's total. The total started at 100 points for all participants at the start of each new schedule presentation. Participants also lost 1 or 10 points for each space bar response, regardless of whether the response was reinforced. This response cost procedure has been adopted in previous studies (Bradshaw & Reed, 2012; Raia et al., 2000).

Participants were randomly allocated to one of two groups: Cost 1 or Cost 10 (both ns = 22). Prior to the task beginning, all participants were presented with instructions on the computer screen (in Chinese):

"*When the task begins, use the space bar to score **as many points as possible**. There are eight games in total. The first game is identified with a large blue [pink] rectangle at the top of the screen. When the first game is over, the rectangle will change to blue [pink] to indicate the start of the next game. The rectangles alternate between blue and pink to*

indicate the changing games for the remainder of the task. Your goal in each game is to

*reach the **highest score possible**. You will see that the points reduce according to the way in*

which you play, but will rise again every so often, according to the pattern of space bar hits

*that you use. All you need to do is to find the best pattern of space bar hits to score **as highly***

***as possible** in each game. It may be a good idea to respond quickly sometimes and slowly at*

other times, but you need to discover this for yourself!"

The participants were then instructed to click a start button to continue with the

experiment. Participants in the Cost 1 group lost one point for each space bar response,

regardless of whether the response was reinforced; and participants in the Cost 10 group lost

10 points for each space bar response, regardless of whether the response was reinforced.

During the time in which they were performing on the schedules, the participants had

to perform a counting backwards task throughout the entire experiment (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 (Bradshaw & Reed, 2012; 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 analysed and scored later.

Results and Discussion

On the first trial of training, the schedule means for the Cost 1 group were: RR =

165.03 ($\pm$ 97.50); RI = 152.86 ($\pm$ 98.36); and these means for the Cost 10 group were: RR =

61.57 ($\pm$ 52.51); RI = 47.93 ($\pm$ 69.55). A two-factor mixed-model analysis of variance

(ANOVA), with cost (1 versus 10) as a between-subject factor, and schedule (RR versus RI)

as a within-subject factor, was conducted on these data. This analysis revealed a statistically

significant main effect of cost, $F(1,42) = 21.32$, $p < .001$, $\eta^2_p = .337[95\%\text{CI} = .121:.502]$,

$pH_1/D = .999$, but not of schedule, $F(1,42) = 1.67$, $p = .203$, $\eta^2_p = .004[.000:.012]$, $pH_0/D =$

.912, or interaction between cost and schedule, $F < 1$, $\eta^2_p = .001[.000:.00]$ $pH_0/D = .999$.

Figure 1 about here

Figure 1 shows the group-mean overall responses rates for final trial, for each

schedule, for each group. Analyses were conducted on the final trial, because it represents

the terminal performance. Inspection of these data shows that, for both schedules, responding

in Cost 1 group was higher than that for Cost 10 group. Moreover, for both groups, RR

schedule response rates were higher than RI schedule response rates. A two-factor mixed-

model ANOVA (cost x schedule) revealed statistically significant main effects of cost,

$F(1,42) = 23.62$, $p < .001$, $\eta^2_p = .360[95\%\text{CI} = .135:.531]$, $pH_1/D = .999$, and schedule,

$F(1,42) = 3.87$, $p = .050$, $\eta^2_p = .084[.000:.263]$, $pH_1/D = .545$. There was no significant

interaction between cost and schedule, $F(1,42) = 2.91$, $p = .095$, $\eta^2_p = .065[.000:.236]$ pH_0/D

$= .581$. These results indicate that participants responded in a differentiated manner

according to schedule types (Chen & Reed, 2020; Peele et al., 1984), and that the response

cost decreased levels of responding (Pietras et al., 2010; Reed et al., 2018).

Figure 2 about here

Figure 2 shows the group-mean bout-initiation (top panel) and within-bout (bottom

panel) rates for two schedules, for the last trial, for both groups. These rates were calculated

using the log survivor method (Shull, 2011), by fitting the double exponential equation:

Ppred = a*exp(-bt)+(1-a)*e(-dt), for each participant individually. Each individual's IRTs were entered into the spreadsheet developed by Peter Killeen (available on the SQAB website, and later modified by Richard Shull). The worksheet fits the data by minimizing the summed squared differences between the logs of obtained and predicted survivor proportions. It also excludes the longest 1% of IRTs, as very long IRTs may result from extra-experimental factors, thus the programme forces a better fit to the right tail – the portion relevant to bout-initiation rate.

Inspection of the group-mean bout-initiation data (top panel) shows that both schedules produced similar rates of responding, but that responding in the Cost 1 group was greater than that to the Cost 10 group. A two-factor mixed-model ANOVA (cost x schedule) revealed a significant main effect of cost, $F(1,42) = 27.23$, $p < .001$, $\eta^2_p = .393[.164:.558]$, $pH_1/D = .736$, but not of schedule, $F(1,42) = 1.62$, $p = .210$, $\eta^2_p = .037[.000:.193]$, $pH_0/D = .999$, and no interaction between schedule and cost, $F < 1$, $\eta^2_p = .000[.000:.000]$, $pH_0/D = .999$. These data replicate previous demonstrations that when the rate of responding is equated on two different schedules, the rate of bout-initiation responding is equal (Chen & Reed, 2020; Killeen et al., 2002; Shull et al., 2001). However, response cost had a pronounced effect on both RR and RI bout-initiations, in line with previous demonstrations of this effect (Reed et al., 2018).

The bottom panel of Figure 2 shows the group-mean within-bout rates for the two groups, for last trial, and reveals response rates in RR schedule are higher than the RI schedule for both groups. The effect of response cost was more pronounced for the RI than for the RR schedule. A two-factor mixed-model ANOVA (group x schedule) revealed statistically significant main effects of schedule, $F(1,42) = 31.02$, $p < .001$, $\eta^2_p = .425[.194:.583]$, $pH_1/D = .999$, but not of cost, $F < 1$, $\eta^2_p = .002[.000:.064]$, $pH_0/D = .999$. There was a significant interaction between cost and schedule, $F(1,42) = 10.14$, $p < .004$, η^2_p

$= .195[.026:.384]$, $pH_0/D = .962$. Simple effect analyses revealed no effect of cost on the RR

schedules, $F(1,42) = 1.92$, $p = .219$, $\eta^2_p = .044[.000:.204]$, $pH_0/D = .694$, but an effect of cost

on the RI schedule, $F(1,42) = 3.37$, $p = .045$, $\eta^2_p = .074[.000:.249]$, $pH_1/D = .503$. These

results demonstrate a higher within-bout rate for the RR compared to the RI schedule (Chen

& Reed, 2020; Reed et al., 2018), but that response cost had an effect only on the RI

schedule.

Overall, these results replicated the effects of RR and RI schedules on human

responding, and also replicated the effects of these schedules on the micro-structure of human

responding (Chen & Reed, 2020; Reed et al., 2018). They also confirmed the effect of the

response cost condition noted in the current Experiment 1 (Pietras et al., 2010; Reed et al.,

2018; Weiner, 1962). It was also noted in the current experiment that the cost manipulation

appeared to differentially impact bout-initiation responding, in comparison with within-bout

responding. The manipulation tended to suppress bout-initiation responses more than it

suppressed within-bout responses (Reed et al., 2018), although this was more true for the RI

than the RR schedule. It has been suggested that the response cost manipulation would

impact the Pavlovian strength of the context, by associating the context with negative

outcomes, as well as positive ones, and, thus, impact bout-initiation responding (Reed et al.

2018; Reed, 2020). Moreover, this effect was stronger for the within-bout responses on the

RI than the RR schedule; the former is taken (overall) to be less goal-directed in nature (Perez

et al., 2016), and perhaps more sensitive to context-driven effects.

Experiment 2

Experiment 2 investigated the effects of both response cost and reinforcement

magnitude on the micro-structure of human schedule behaviour. Experiment 1 demonstrated

that higher response costs impacted bout-initiation responding to a much greater extent than within-bout responding (see also Reed et al., 2018). This was in line with predictions based on the assumption that response cost would impact context conditioning and stimulus-driven responding more than goal-directed responding (Reed et al., 2018). Experiment 2 examined whether this effect of response costs on bout-initiation responding could be replicated.

Magnitude of reinforcement also has been suggested to impact instrumental responding (Gentry & Eskew, 1984; Hendry, 1962; but see Bonem & Crossman, 1988; Reed, 1991). However, there are very few studies that investigate the effects of reinforcement magnitude for human participants (see Blakely, Starin, & Poling, 1988), or which explore the interaction between the response cost and reinforcement magnitude on the micro-structure of responding for human participants or, indeed, any species. In terms of the predicted effect of reinforcement magnitude, this factor has been suggested to both energise overall levels of activity (Killeen, 1985) through conditioning goal-related/contextual cues (Pereboom & Crawford, 1958), and to strengthen goal-directed behaviour (Reed, 1991). Given this, in contrast to response cost (which is taken to act more on bout-initiation than within-bout responses), reinforcement magnitude should act on both types of responses.

To this end, participants were randomly split into four experimental groups: Cost 1 Reinforcement 40; Cost 1 Reinforcement 600; Cost 10 Reinforcement 40; and Cost 10 Reinforcement 600. They then responded on a RR-30 RI-y schedules, as in Experiment 1, and their responses analysed using the log survivor method (Killeen et al., 2002).

Method

Participants

A sample of 105 students (39 males, 65 females) were recruited from two universities (55 from China and 50 from the UK). None of the participants were involved in Experiment

1. They were aged between 18 to 36 years (mean= 19.76 $\pm$ 1.99). Participants received

credits from the University subject pool. No participant reported any previous history of

mental illness. However, 7 participants were excluded on this basis of their psychometric

depression or schziotypy scores (as described in Experiment 1), leaving 98 in the study (Cost

1 Rein 40 = 25; Cost 1 Rein 600 = 22; Cost 10 Rein 40 = 24; Cost 10 Rein 600 = 27). The

apparatus and materials were as described in Experiment 1.

Procedure

The procedure was as described in Experiment 1, except that the participants were

randomly divided into four groups: (Cost 1 Rein 40; Cost 1 Rein 600; Cost 10 Rein 40; Cost

10 Rein 600). All groups responded on the RR-30 RI-y schedule, and experienced 4 pairs of

RR and RI training. Each trial lasted 4 min (i.e. there were 8 x 4-min trials in total). All

participants initially started with 100 points, which was reset at the start of each trial. For

Group Cost 1 Rein 40, each response subtracted 1 point from their total, and a reinforcer

consisted of 40 points being added to the total. For Group Cost 1 Rein 600, each response

subtracted 1 point from their total, and a reinforcer consisted of 600 points being added to the

total. For Group Cost 10 Rein 40, each response subtracted 10 points from their total, and a

reinforcer consisted of 40 points being added to the total. For Group Cost 10 Rein 600, each

response subtracted 10 points from their total, and a reinforcer consisted of 40 points being

added to the total.

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Results and Discussion

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On the first trial of training, the schedule means for the Cost 1 Rein 40 group were:

RR = 136.12 ($\pm$ 57.21), RI = 129.76 ($\pm$ 72.61); Cost 1 Rein 600: RR = 165.32 ($\pm$ 82.54), RI =

154.34 ($\pm$ 42.11); Cost 10 Reinf 40: RR = 68.21 ($\pm$ 52.61), RI = 63.43 ($\pm$ 49.18); Cost 10

Rein 600: RR= 147.32 ($\pm$ 54.34), RI = 132.45 ($\pm$ 44.76). A three-factor mixed-model

ANOVA (schedule x cost x reinforcement) revealed a statistically significant main effect of

cost, $F(1,93) = 11.14$, $p < .001$, $\eta^2_p = .102[.030:.220]$, $pH_1/D = .976$, and reinforcement,

$F(1,93) = 8.86$, $p = .021$, $\eta^2_p = .089[.005:.123]$, $pH_1/D = .856$, but not schedule, $F < 1$, $\eta^2_p =$

$.007[.000:.023]$, $pH_0/D = .970$. There were no two-way or three-way interactions, all, Fs <

1, largest $\eta^2_p = .006[.000:.069]$, all $pH_0/D > .990$.

Figure 3 about here

Figure 3 shows the group-mean overall responses rates for final trial, for each

schedule, for each of the four groups. Inspection of these data shows that responding to the

RR schedule was higher than that to the RI schedule, responding in 1-point cost groups was

higher than that for 10-point cost groups, and responding in the 600-point reinforcement

groups was higher than that in the 40-point reinforcement groups. A three-factor mixed-

model ANOVA (schedule x cost x reinforcement) revealed statistically significant main

effects of schedule, $F(1,93) = 14.04$, $p < .001$, $\eta^2_p = .132[.030:.260]$, $pH_1/D = .990$, cost,

$F(1,93) = 10.32$, $p = .002$, $\eta^2_p = .100[.015:.223]$, $pH_1/D = .946$, and reinforcement, $F(1,93) =$

13.79, $p < .001$, $\eta^2_p = .129[.029:.257]$, $pH_1/D = .989$. There were no two-way interactions:

schedule and cost, $F < 1$, $\eta^2_p = .009[.000:.079]$ $pH_0/D = .865$; schedule and reinforcement,

$F(1,93) = 1.40$, $p = .238$, $\eta^2_p = .014[.000:.094]$, $pH_0/D = .826$; cost and reinforcement,

$F(1,93) = 2.85$, $p = .095$, $\eta^2_p = .029[.000:.123]$, $pH_0/D = .692$, or three-way interaction, $F < 1$,

$\eta^2_p = .001[.000:.013]$, $pH_1/D = .907$.

These results indicate that participants responded in a differentiated manner according

to schedule types (Chen & Reed, 2020; Peele et al., 1984; Zuriff, 1970), and that the response

cost decreased levels of responding (Reed et al., 2018; Weiner, 1964; and the current

Experiment 1). In addition, reinforcement magnitude increased rates of responding. This latter effect has been noted for human participants (Blakely et al., 1988), but is not always observed (Bonem & Crossman, 1988; Reed, 1991).

Figure 4 about here

Figure 4 shows the group-mean bout-initiation (top panel) and within-bout (bottom panel) rates for two schedules, for the last trial, for all groups, using the survivor method (Killeen et al., 2002), as described in Experiment 1. Inspection of the group-mean bout-initiation data (top panel) shows that both schedules produced similar rates of responding, but that responding in 1-point cost groups was greater than that in the 10-point cost groups. Rates of bout-initiation were higher in the 600-point reinforcement groups, than in the 40-point reinforcement groups.

A three-factor mixed-model ANOVA (schedule x cost x reinforcement) revealed statistically significant main effects of cost, $F(1,93) = 12.65$, $p < .001$, $\eta^2_p = .120[.023:.246]$, $pH_1/D = .981$, and reinforcement, $F(1,93) = 13.90$, $p < .001$, $\eta^2_p = .130[.029:.258]$, $pH_1/D = .989$, but not of schedule, $F < 1$, $\eta^2_p = .004[.000:.066]$, $pH_0/D = .889$. There were no two-way interactions: schedule and cost, $F(1,93) = 1.55$, $p = .215$, $\eta^2_p = .016[.000:.098]$ $pH_0/D = .814$; schedule and reinforcement, $F < 1$, $\eta^2_p = .016[.000:.098]$, $pH_0/D = .892$; cost and reinforcement, $F(1,93) = 1.82$, $p = .181$, $\eta^2_p = .019[.000:.104]$, $pH_0/D = .793$, or three-way interaction, $F(1,93) = 2.97$, $p = .088$, $\eta^2_p = .031[.000:.125]$, $pH_1/D = .679$.

These data replicate previous demonstrations that when the rate of responding is equated on two different schedules, the rate of bout-initiation responding is equal (Chen & Reed, 2020; Reed, 2015; Shull, 2011). However, increasing the response cost decreased the rate of bout-initiations, consistent with the results of Experiment 1 (see also Reed et al.,

2018). Increasing the level of reinforcement increased the bout-initiation rate. This is a novel finding, but is predictable on the basis of reinforcement magnitude increasing the level of context conditions (Killeen, 1985; Pereboom & Crawford, 1958).

The bottom panel of Figure 4 shows the group-mean within-bout rates for all groups, and reveals within-bout response rates in RR schedule were higher than the RI schedule for all groups. Increasing the magnitude of reinforcement increased within-bout rates, and increasing response costs decreased rates, but not in as strong a manner as reinforcement magnitude increased these rates.

A three-factor mixed-model ANOVA (schedule x cost x reinforcement) revealed statistically significant main effects of schedule, $F(1,93) = 18.74$, $p < .001$, $\eta^2_p = .168[.051:.300]$, $pH_1/D = .788$, reinforcement, $F(1,93) = 14.00$, $p < .001$, $\eta^2_p = .131[.030:.259]$, $pH_1/D = .990$, and a smaller effect of cost, $F(1,93) = 4.49$, $p = .037$, $\eta^2_p = .046[.000:.152]$, $pH_1/D = .505$. There were no two-way interactions: schedule and cost, $F < 1$, $\eta^2_p = .003[.000:.061]$ $pH_0/D = .893$; schedule and reinforcement, $F < 1$, $\eta^2_p = .008[.000:.079]$, $pH_0/D = .864$; cost and reinforcement, $F < 1$, $\eta^2_p = .008[.000:.079]$, $pH_0/D = .903$, or three-way interaction, $F(1,93) = 2.32$, $p = .129$, $\eta^2_p = .024[.000:.113]$, $pH_1/D = .745$.

These results demonstrate a higher within-bout rate for the RR compared to the RI schedule (Chen & Reed, 2020; Shull, 2011). They also show that reinforcement magnitude appears to control within-bout rates, which might be expected if it is assumed that this form of response is goal-directed, and magnitudes of reinforcement not only impact stimulus-driven responding, but also impact goal-directed behaviour (Killeen, 1985; Reed, 1991). Although numerically similar to the data reported in Experiment 1, there was no statistical differentiation between the effect of response cost on RI and RR schedules.

General Discussion

This current series of experiments examined the effects of a number of factors, taken to control free-operant performance, on the micro-structure of human schedule behaviour. In particular, response cost and reinforcer magnitude were examined in relation to predictions based on the nature of bout-initiation and within-bout responding. It was hypothesised that bout-initiation responding would be controlled by factors affecting context-conditioning that could control bout-initiation responding through stimulus-driven means. In contrast, it was suggested that within-bout responses were goal-directed, and would be impacted by factors strengthening responding. In addition to demonstrating the empirical effects of manipulating the above aspects of the contingency on human schedule performance, which is itself novel, this investigation explored some theoretical underpinnings to the micro-structure of human responding.

The current results demonstrated that human responding on RR and RI schedules of reinforcement, yoked in terms of reinforcement rate, followed the same pattern as noted for nonhuman subjects (Peele et al., 1984; Zuriff, 1970); overall responding was higher for the RR than the RI schedules (see also Chen & Reed, 2020; Reed et al., 2018). It was noted that bout-initiation rates were not different across the two schedules in either Experiment 1 or 2. This replicates previous findings with nonhuman subjects (Reed, 2011; Shull et al., 2001) with human participants (Chen & Reed, 2020; Reed et al., 2018). In contrast, within-bout rates were higher on the RR than the RI schedule. Again, replicating previous findings from nonhuman subjects (Reed, 2011; Shull, 2011), and human participants (Reed et al., 2018).

One explanation for this differential impact of schedules on the micro-structure of schedule-controlled responding is that bout-initiation responses are controlled by the rate of reinforcement received in the context (Shull, 2011), but that within-bout responses are

controlled by factors like IRT reinforcement (Peele et al., 1984). Reed et al. (2018) suggested that these facts could be accommodated by suggesting that bout-initiation responding was stimulus-driven, and the strength of the context was a prime determinant of this action; but within-bout responding is goal-directed and that response-strengthen effects control this type of responding. The current series of studies attempt to determine if a series of manipulations would support this suggestion.

Response cost was examined in both Experiments 1 and 2, and was found to reduce overall rates of responding (Pietras & Hackenberg, 2005; Raiff et al., 2008). This is in line with the results from previous studies for nonhuman subjects (McMillan, 1967; Pietras et al., 2010) and human participants (Reed, 2001; Weiner, 1964). However, this manipulation tended to suppress bout-initiation responding more than within-bout responding (Reed et al., 2018); although there was some impact on the latter in Experiment 2. This differential suppressive effect is consistent with response cost effecting the Pavlovian value of the context, and, thus, impacting responses on more stimulus-driven, bout-initiation responses (Reed et al., 2018).

The effect of reinforce magnitude was to increase rates of responding (Experiment 2). Many previous researchers have found a positive correlation between reinforcer magnitude and human participants' response rates (Buskist et al., 1988; Hendry, 1962; Gentry & Eskew, 1984), although this is not always noted (Bonem & Crossman, 1988; Reed, 1991). At the level of the micro-structure of responding, the effect of reinforcement magnitude was suggested to be both on bout-initiation and within-bout responding. This effect was noted in Experiment 2. Reinforcement magnitude has been suggested to have dual impacts on responding (Killeen, 1985). Firstly, to increase the likelihood of activity (Killeen, 1985) through conditioning goal-related cues (Pereboom & Crawford, 1958), which should impact bout-initiation responding. Secondly, to act directly on goal-directed behaviour to strengthen

to tendency to emit the preceding responses (Reed, 1991). These predictions were in line with the current findings.

It should be noted that the log survivor procedure avoids arbitrary selection of cut-off values to categorise responses into bout-initiation and within-bout classes (Reed, 2020), but it relies on assumptions about the fit of the equation to the data (Bowers, Hill, & Palya, 2008), and it is not clear if there may be other equations more appropriate for human responding. Additionally, the double exponential method (Shull, 2011) requires many IRTs to get very precise parameter estimates. The current samples were somewhat smaller than those typically used from nonhuman subjects, and the resulting imprecision is likely to underestimate within-bout response rate is acknowledged. Nevertheless, this method has the best documented association with the factors that influence the 'bout-initiation' and 'within-bout' responding – the main aim of the current study.

It should be acknowledged that while the reverse-counting task may have mitigated the possibility that behavior was rule-governed, this cannot be discounted entirely. For example, the last statement of the instructions advised: "It may be a good idea to respond quickly sometimes and slowly at other times", and this mirrored the order of the schedule presentation. If participants followed the rules in the order that they were given, they would come into contact with the fact that higher rates of responding would produce higher rates of point delivery under the RR schedule, which was the first "game" presented. As they were also instructed that there were two games, when the rectangle changed colours, they could follow the rule that it was the next game, and maybe "slowly at other times" was now in effect. Varying the instructions may serve to further explore these possibilities. It may also be the case that longer exposure to the schedules might have impacted the results, although that there was little impact of schedule control on the first trials, and there subsequently was such an impact, suggests some learning had occurred.

Thus, the current data were consistent with the suggestion that bout-initiation responding co-varies with overall rates of reinforcement (Killeen et al., 2002; Shull, 2011; Shull et al., 2001), and is stimulus-driven (Reed, 2020), controlled by the degree to which the context gains strength (Reed et al., 2018). 'Within-bout' responding is influenced by the shaping effects of reinforcement on responding (Reed et al., 2018; Shull, 2011), and is goal-directed (Reed, 2020).

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Figure 1: Experiment 1: Group-mean overall response rates for RR and RI schedules for both groups (1 point response cost and 10 point response cost) on the final trial of training. Error bars = 95% confidence intervals.
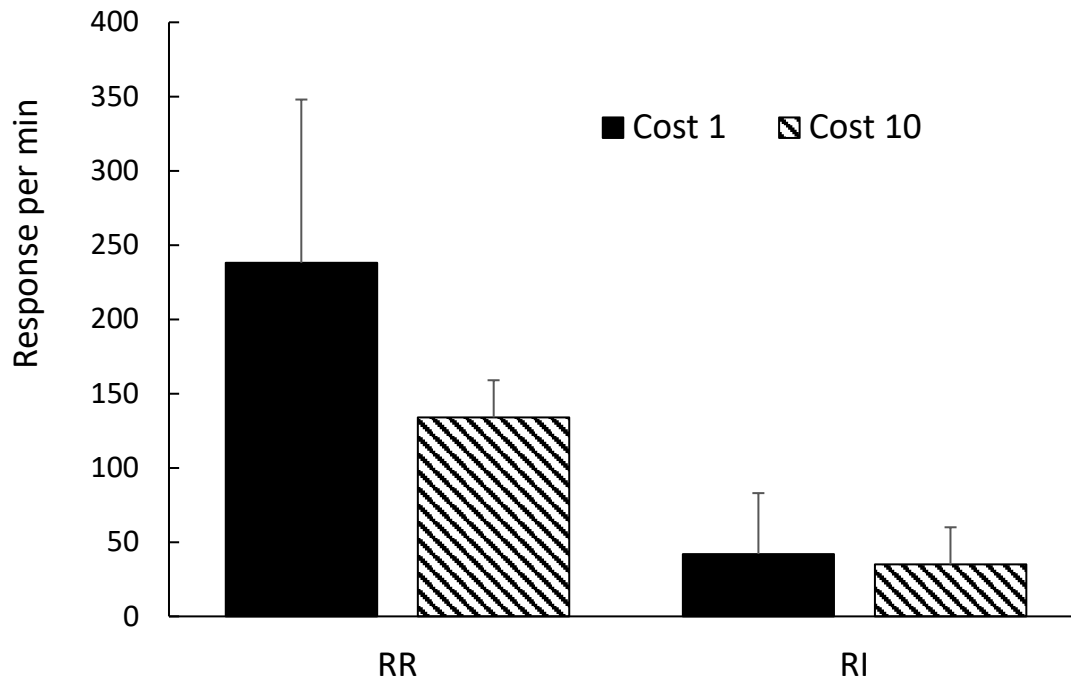
Figure 2: Experiment 1: Group-mean response rates for RR and RI schedules both groups (1 point response cost and 10 point response cost) on the last trial, using the log survivor method. Top panel = response initiation rates. Bottom panel = within-bout rates. Error bars = 95% confidence intervals.
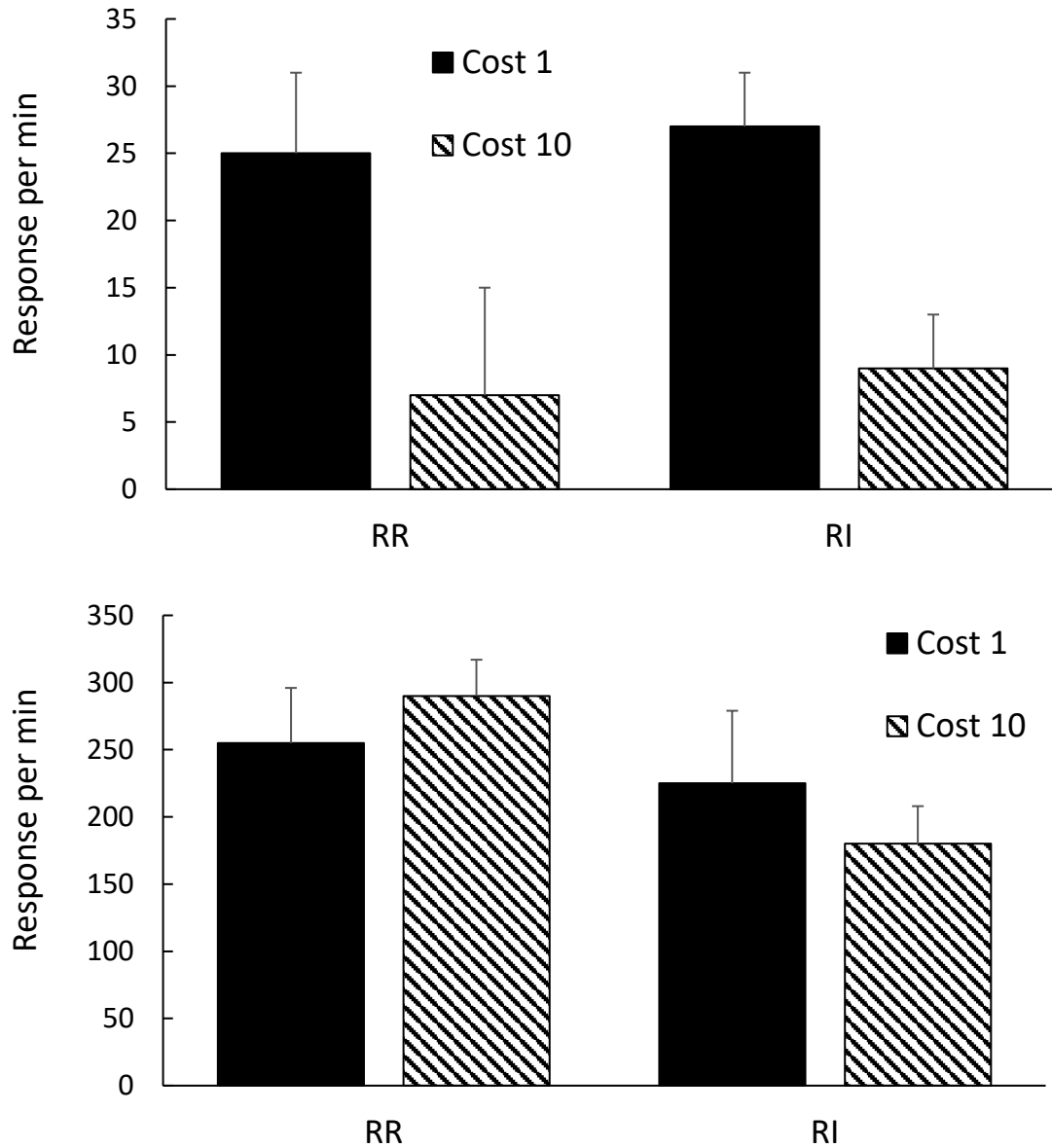
Figure 3: Experiment 2: Group-mean overall response rates for RR and RI schedules for all groups (cost = response cost; Rein = reinforcement magnitude) on the final trial of training. Error bars = 95% confidence intervals.
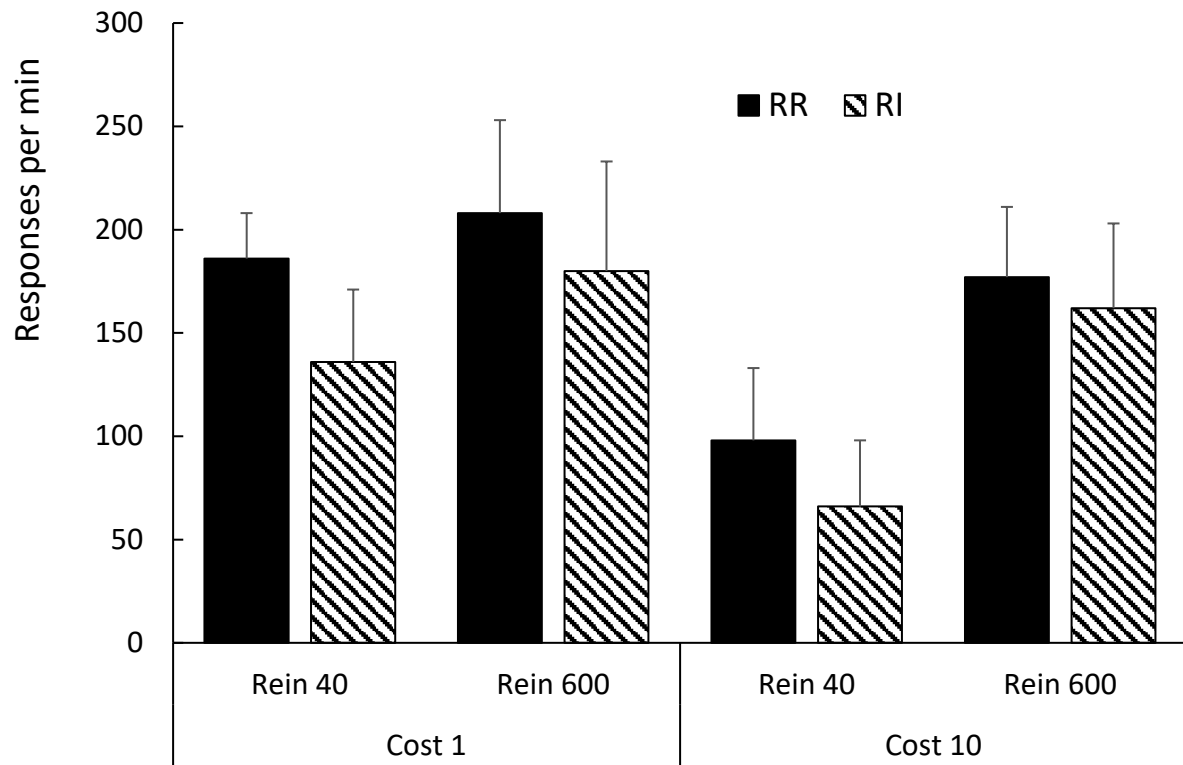
Figure 4: Experiment 2: Group-mean response rates for RR and RI schedules both groups (cost = response cost; Rein = reinforcement magnitude) on the last trial, using the log survivor method. Top panel = response initiation rates. Bottom panel = within-bout rates. Error bars = 95% confidence intervals.